

Cape T Stern Ramp: Summary of Structural Dynamics

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Prepared for:

NSWC – Carderock

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Naval Architect



Cape T Analyses Performed

- All analyses were performed using a NASTRAN model provided to NPS. This model includes a lumped mass/rigid-element representation of a single tank. No isolation/compensation between ramp and barge.
- Natural frequencies and mode shapes were calculated up to 10 Hz.
- Dynamic stress calculated due to prescribed RORO (barge) motions.
 - Wave-induced RORO motions applied (Sea State 3):
 - Cape T assumed motionless
 - Barge heave and roll (separate load cases)
 - Prescribed motion frequencies: 0.05 Hz, 0.15 Hz, 0.25 Hz, 0.35 Hz.
 - Wave amplitude 2.5 ft (5 ft peak-to-peak)
 - Worst case: barge roll input at 0.35 Hz
 - Very large stresses ($\sim 10^5$ psi) found for imposed Sea-State 3 roll angles
- Determined stress-limited barge roll angle :
 - For max ramp stress of 40 kpsi, max barge roll angle is 1.032 degrees

Summary of Results



- Cape T assumed fixed. No barge-ramp isolation.
- Ramp mode periods significantly below wave periods.
Ramp exhibits pseudo-static response
- Very large peak stresses predicted for Sea-State 3 wave-induced barge roll angles
- Small stresses predicted for Sea-State 3 wave-induced barge heave displacements
- Typical allowable stress for steel limits barge roll angles to approx. 1 degree

Natural Modes

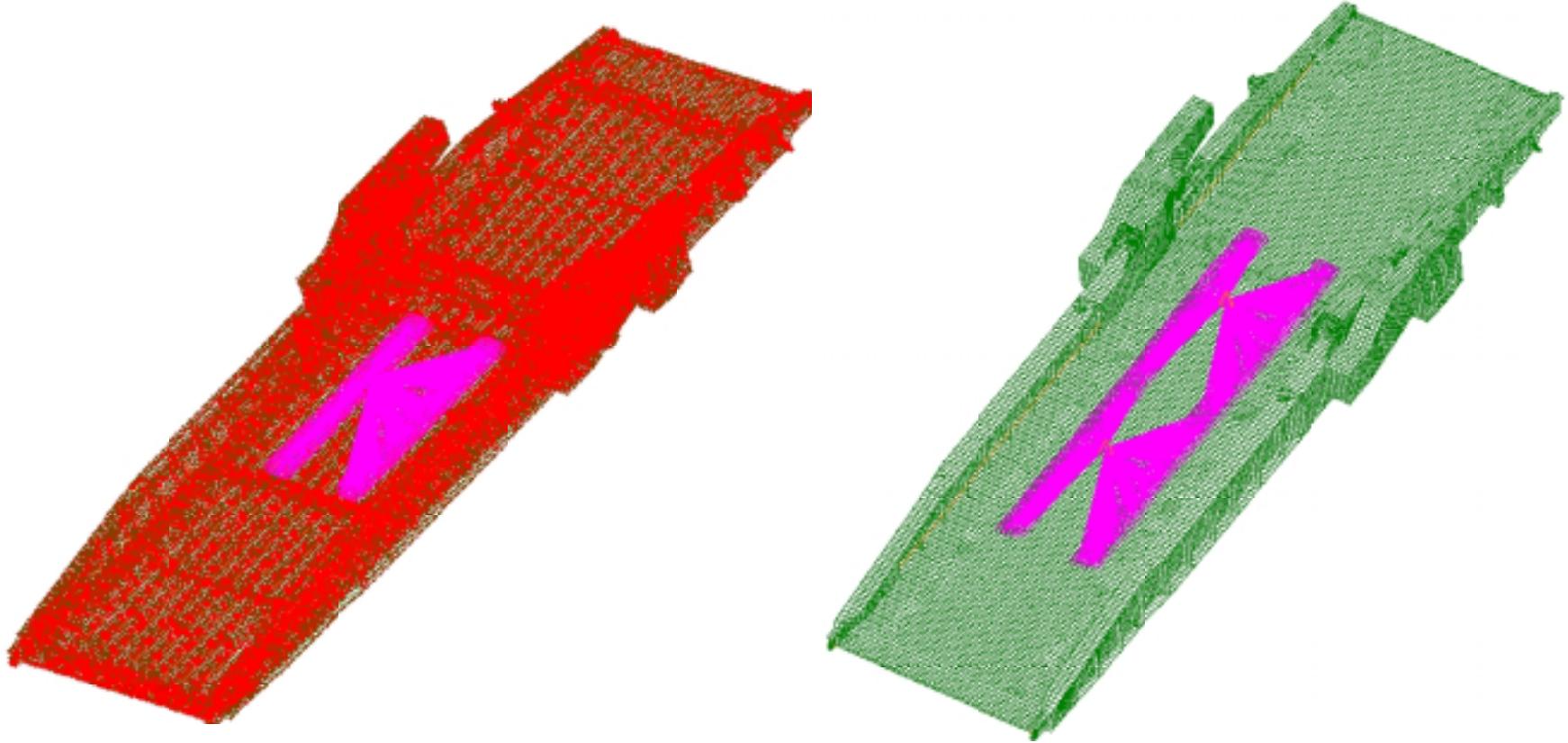
- **Vehicle loading analyzed:**
 - One tank (80.41 ton added mass)
 - Two tanks (160.82 ton added mass)
- **Boundary conditions analyzed:**
 - Pin restraints at hinge-line ends
 - As-delivered (Case #1)
 - As-delivered + ship-end vertical pins (Case #2)
 - As-delivered + barge-end vertical pins (Case #3)
 - As-delivered + barge & ship-end vertical pins (Case #4)
 - Fully-pinned at ship end + barge end vertical pins (Case #5)

Dynamic Stress

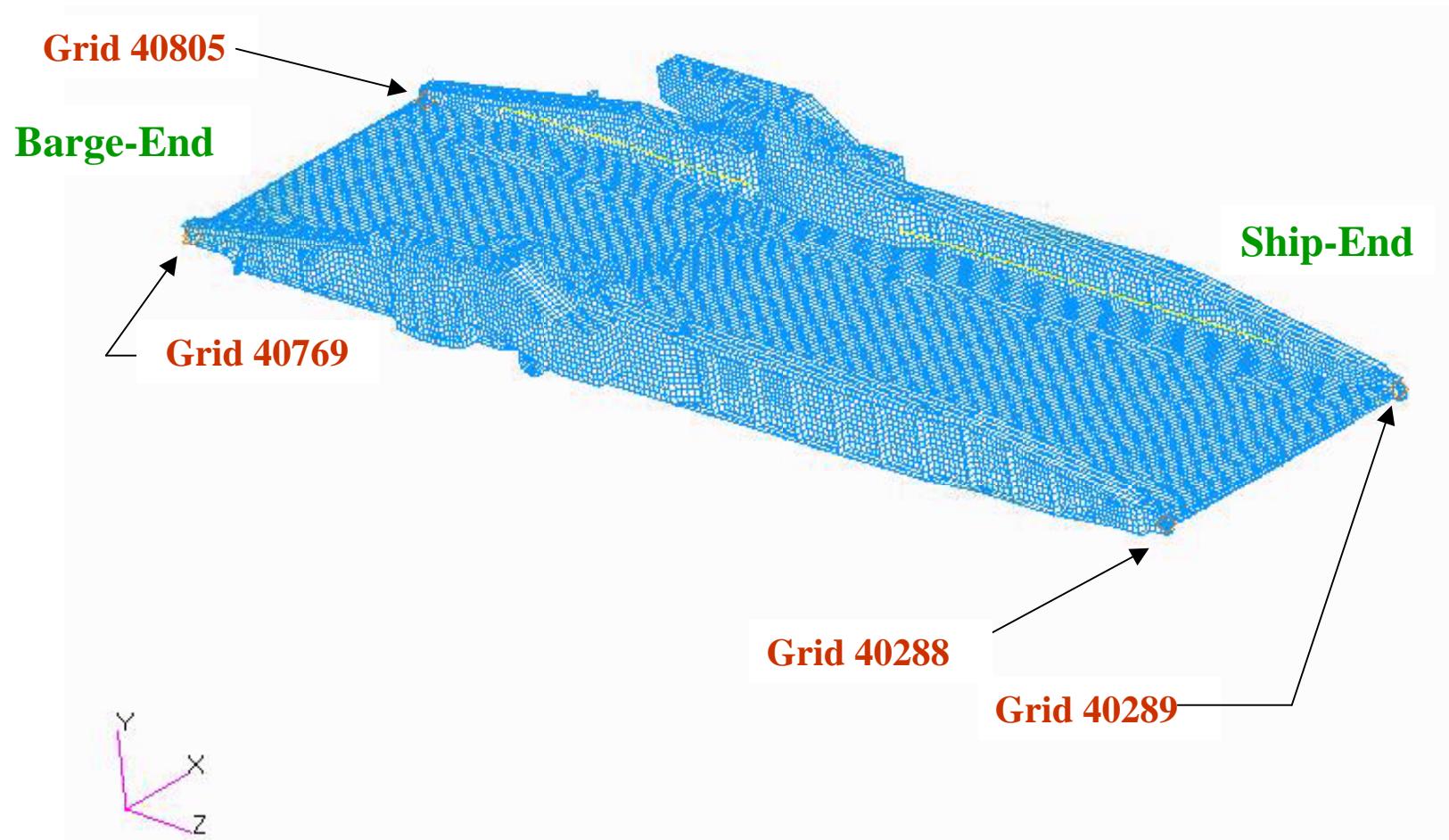
- **Vehicle loading analyzed:**
 - No tank
 - One tank (80.41 ton added mass)
 - Two tanks (160.82 ton added mass)
- **Boundary conditions analyzed:**
 - Pin restraints at hinge-line ends
 - Fully-pinned at ship end + barge end vertical pins (Case #5)

Cape T – One Tank & Two Tanks

- Two tanks centered about as-delivered single tank position

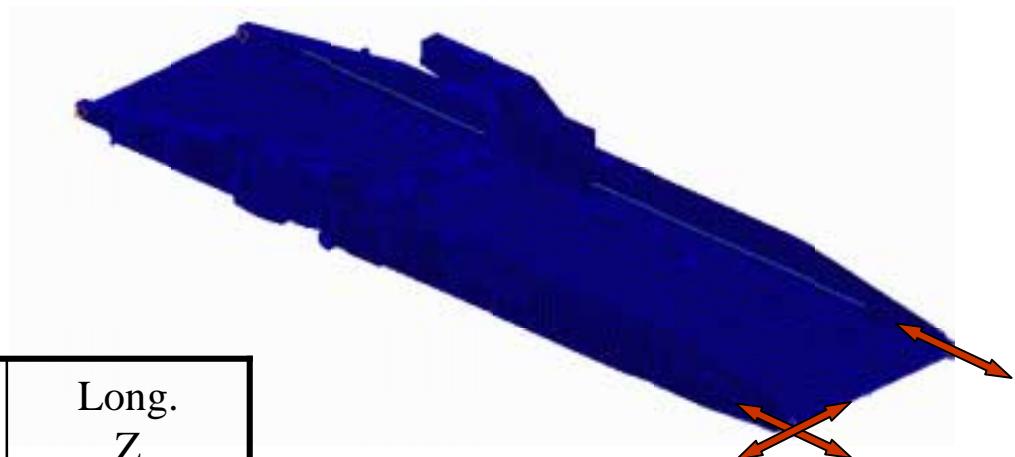


Boundary Condition Gridpoints



Boundary Condition Case #1

- As-delivered (model as received):

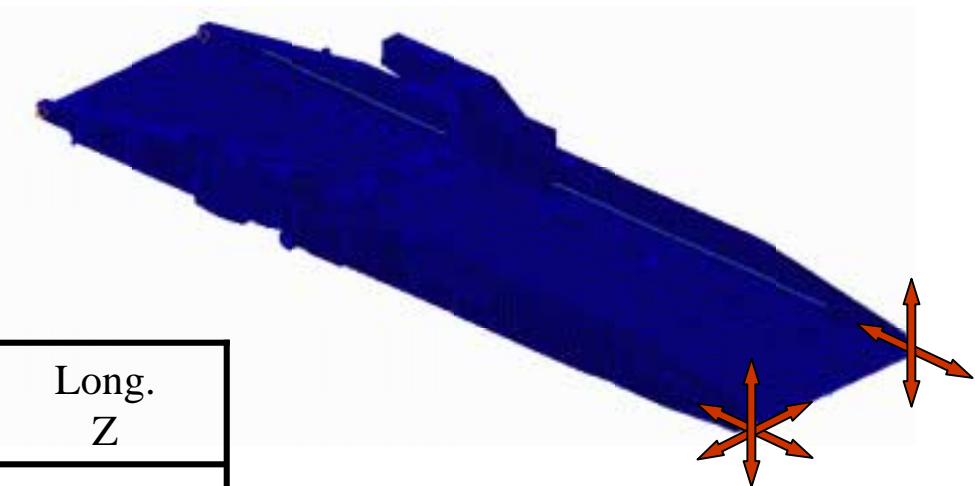


Arrows indicate restrained DOF

Grid	Lateral X	Vertical Y	Long. Z
40288	➡		➡
40289			➡
40769			
40805			

Boundary Condition Case #2

- As-delivered + ship-end vertical pins:

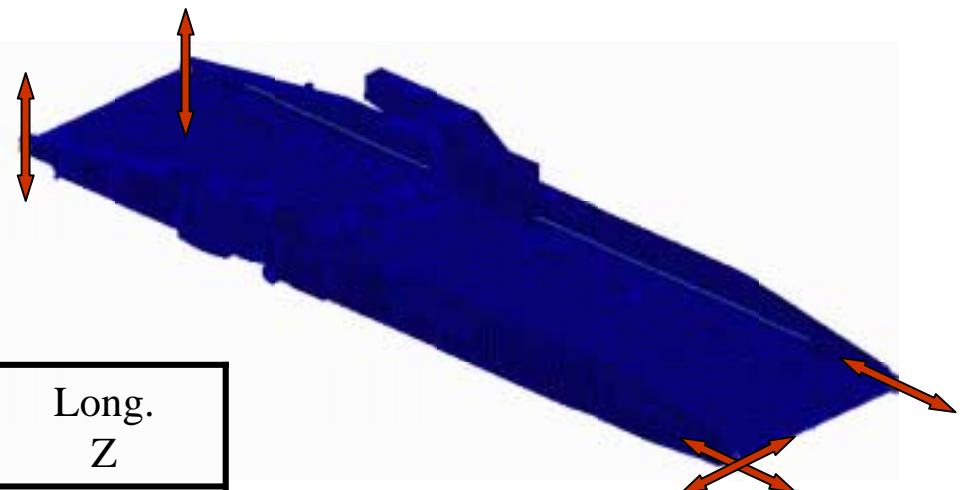


Arrows indicate restrained DOF

Grid	Lateral X	Vertical Y	Long. Z
40288	►	►	►
40289		►	►
40769			
40805			

Boundary Condition Case #3

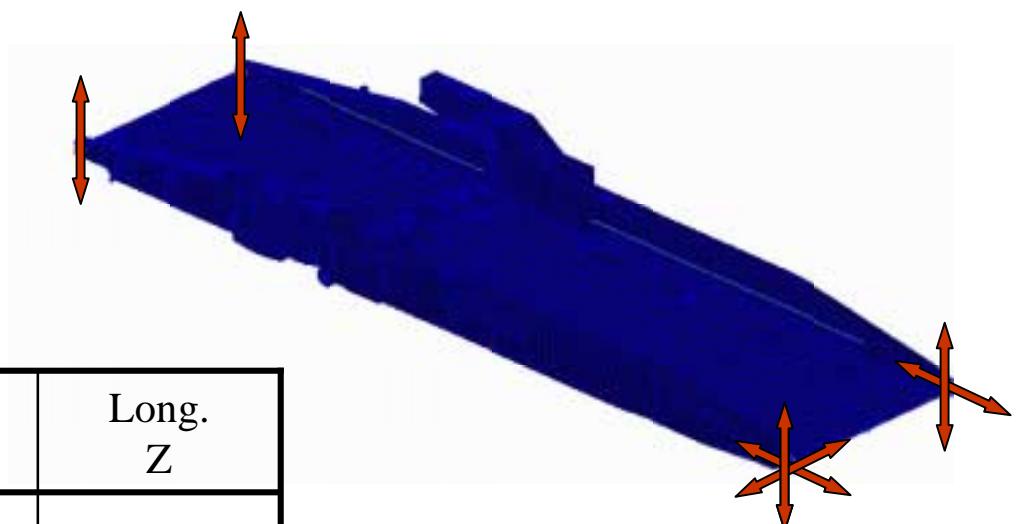
- As-delivered + barge-end vertical pins



Grid	Lateral X	Vertical Y	Long. Z
40288	➡		➡
40289			➡
40769		➡	
40805		➡	

Boundary Condition Case #4

- As-delivered + four vertical pins

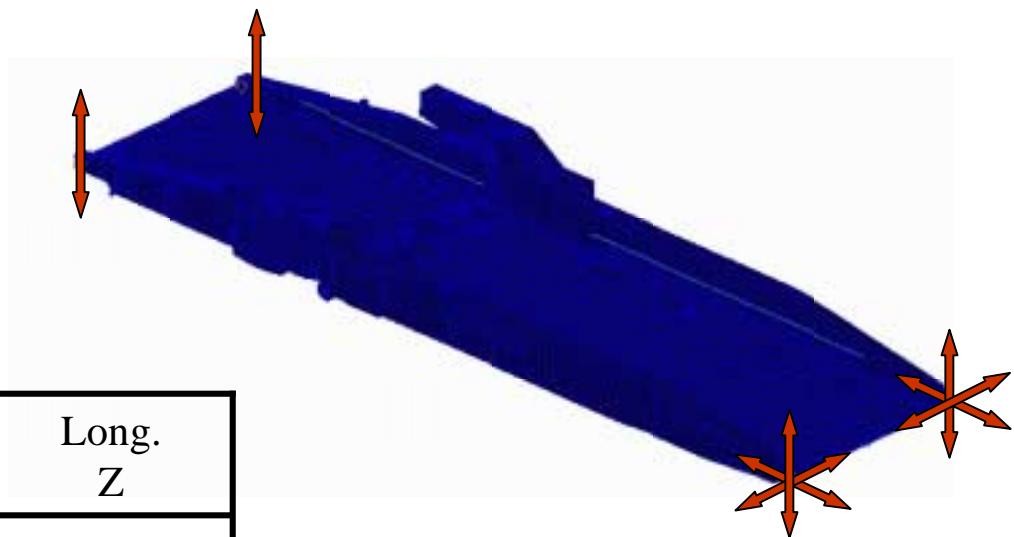


Grid	Lateral X	Vertical Y	Long. Z
40288	➡	➡	➡
40289		➡	➡
40769		➡	
40805		➡	

Arrows indicate restrained DOF

Boundary Condition Case #5

- Fully-pinned at ship end + vertical pins barge end



Arrows indicate restrained DOF

Grid	Lateral X	Vertical Y	Long. Z
40288	➡	➡	➡
40289		➡	➡
40769		➡	
40805		➡	

Natural Frequency Summary

- All modes to 10 Hz calculated
- One & Two Tank results

As-Delivered		As-Deliv. + Vert. Pins Barge		As-Deliv. + Vert. Pins Ship-End		As-Deliv. + Vert. Pins Ship & Barge		Full Pins Ship End Vert. Pins Barge		
	Case #1		Case #2		Case #3		Case #4		Case #5	
	One Tank	Two Tanks	One Tank	Two Tanks	One Tank	Two Tanks	One Tank	Two Tanks	One Tank	Two Tanks
Mode 1	0.00	0.00	0.00	0.00	0.00	0.00	2.26	2.10	2.26	2.10
Mode 2	0.00	0.00	1.05	1.49	1.15	1.48	2.85	2.58	2.86	2.62
Mode 3	0.00	0.00	3.17	2.79	3.46	3.15	3.49	3.35	3.61	3.45
Mode 4	2.44	2.69	4.35	4.23	4.65	4.19	8.20	6.64	8.20	6.65
Mode 5	4.26	5.91	6.71	8.21	5.84	7.81	9.11	9.91	9.20	9.91
Mode 6	6.87	6.96	9.18	8.75	9.30	8.42				
Mode 7	8.12	9.93	9.51							

Red Frequencies – Torsion Mode

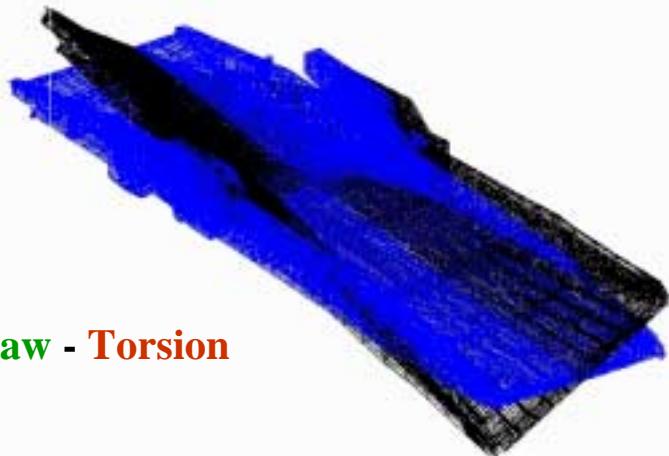
Blue Frequencies – Bending Mode

Green Frequencies – Yaw Mode

Note: The **yellow** modes are combined yaw + torsion. These modes are labeled “Yaw” as they are either dominated by yaw motion, or have a significant yaw component.

MSC.Patran 2000 (25-Feb-01 10:19:40)

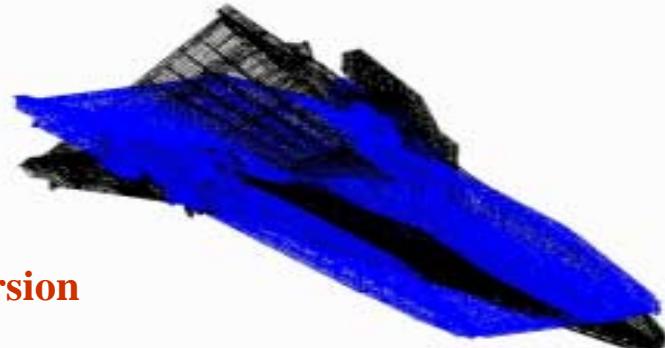
Deform: As-Delivered BC; Mode 4; Freq = 0.036; Eigenvectors; Translational



Yaw - Torsion

MSC.Patran 2000 (25-Feb-01 10:30:04)

Deform: As-Delivered BC; Mode 5; Freq = 0.2563; Eigenvectors; Translational



Torsion

MSC.Patran 2000 (25-Feb-01 10:21:10)

Deform: As-Delivered BC; Mode 6; Freq = 0.0738; Eigenvectors; Translational



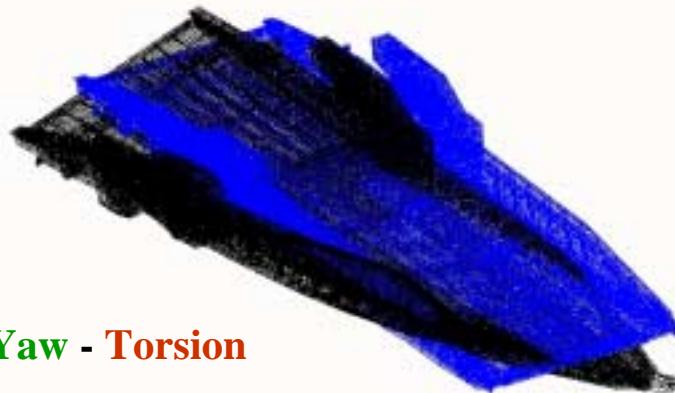
Bending

deform_Deformation
Mode T25-003 (@Node 57482)

Boundary Condition Case #1 One Tank First 3 Elastic Modes

MSC Poten2308 r208 Feb-01 1412 #6

Debris Two Tanks - Case #1: Mode 4 Freq=2.6371 Eigenvector, Time Unconstrained

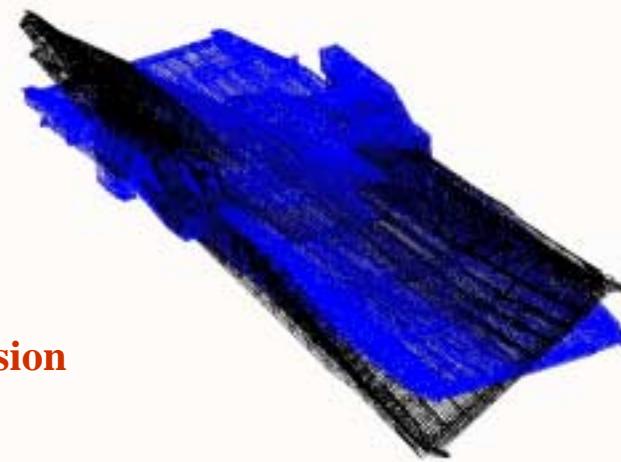


Yaw - Torsion



MSC Poten2308 r208 Feb-01 1411 #6

Debris Two Tanks - Case #1: Mode 5 Freq=5.9134 Eigenvector, Time Unconstrained

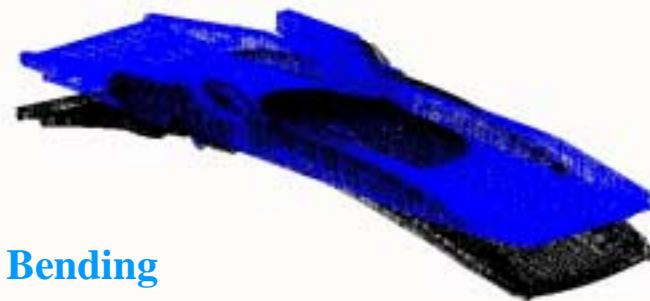


Torsion



MSC Poten2308 r208 Feb-01 1414 #6

Debris Two Tanks - Case #1: Mode 6 Freq=6.5612 Eigenvector, Time Unconstrained

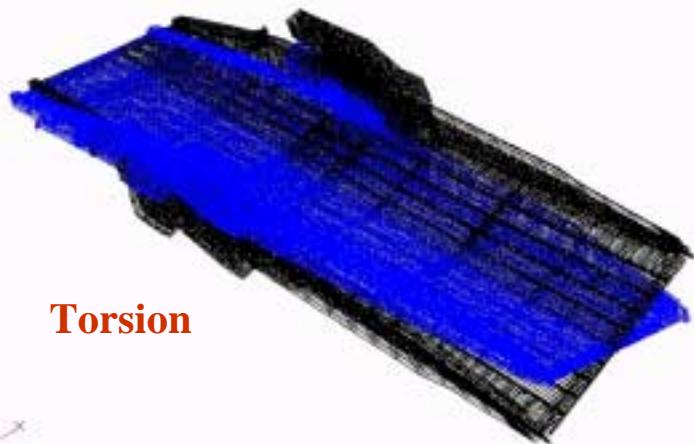


Bending



Boundary Condition Case #1 Two Tanks First 3 Elastic Modes

MSC.Poten3308 r208 Feb-01 11:25 4C
Detors Case #2: Mode 2 Freq=1.0542 Eigenvectors, Translational



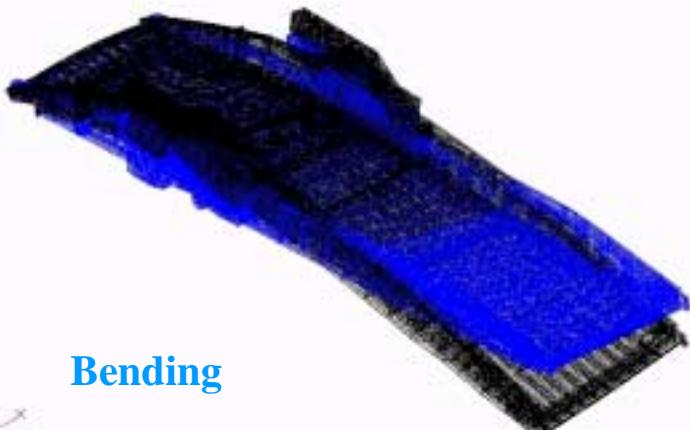
Torsion

MSC.Poten3308 r208 Feb-01 11:28 3C
Detors Case #2: Mode 3 Freq=1.1167 Eigenvectors, Translational



Yaw - Torsion

MSC.Poten3308 r208 Feb-01 11:28 5T
Detors Case #2: Mode 4 Freq=4.3453 Eigenvectors, Translational



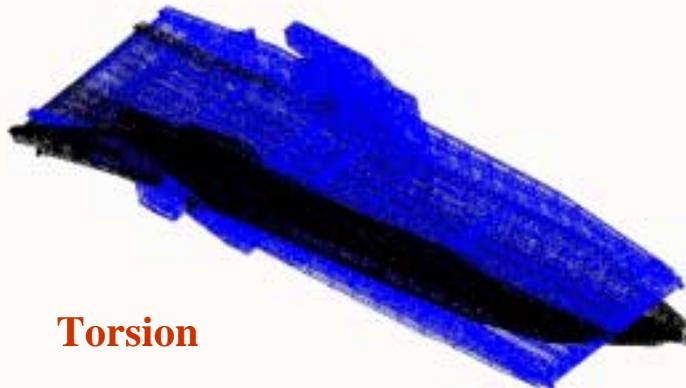
Bending

default_Decomposition
Max 0.09-0.03 @Node 21090

Boundary Condition Case #2 One Tank First 3 Elastic Modes

MSC.Poten2308r208-File#01.14.0218

Debore Two Tanks - Case #2 Mode 2 Freq=1.4854 (Eigenvectors, Time Harmonic)



Torsion



MSC.Poten2308r208-File#01.14.02187

Debore Two Tanks - Case #2 Mode 4 Freq=4.2202 (Eigenvectors, Time Harmonic)

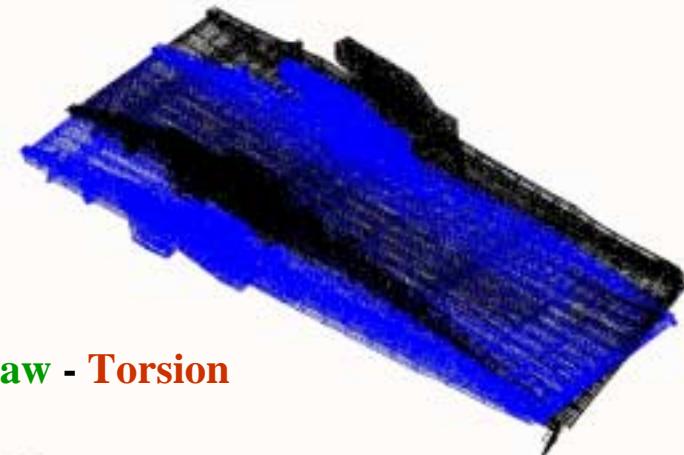


Bending



MSC.Poten2308r208-File#01.14.0218

Debore Two Tanks - Case #2 Mode 2 Freq=0.7381 (Eigenvectors, Time Harmonic)



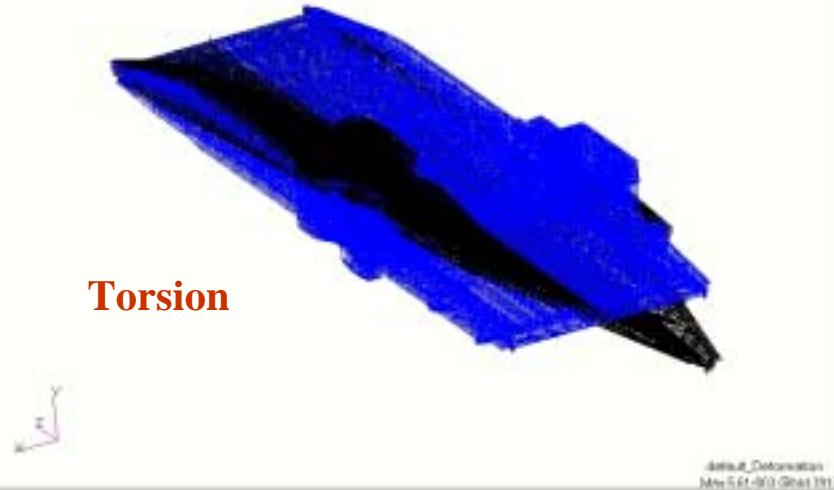
Yaw - Torsion



Boundary Condition Case #2 Two Tanks First 3 Elastic Modes

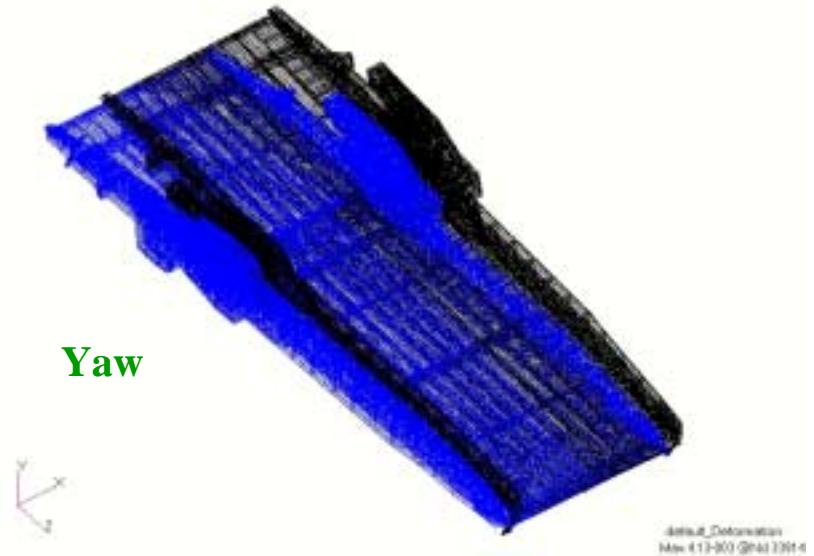
MSC.Poten2908r2/0-Feb-01 13:04:42:

Detors One Tank - Case #3 Mode 2 Freq=1.1458 (Eigenvectors, Translational)



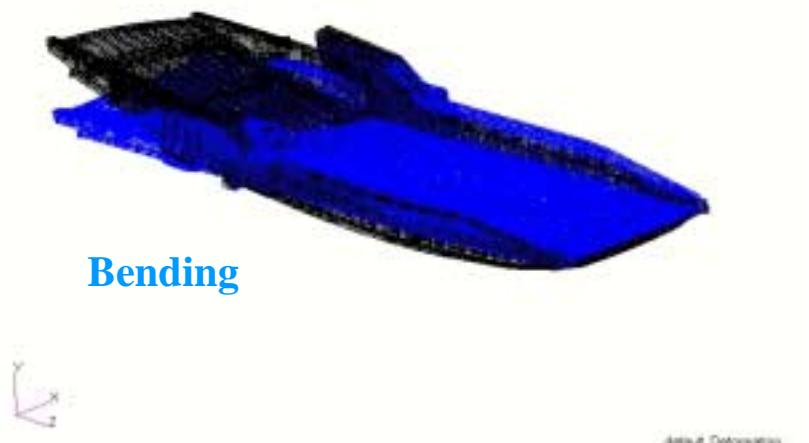
MSC.Poten2908r2/0-Feb-01 13:17:36:

Detors One Tank - Case #3 Mode 3 Freq=1.4562 (Eigenvectors, Translational)



MSC.Poten2908r2/0-Feb-01 13:18:56:

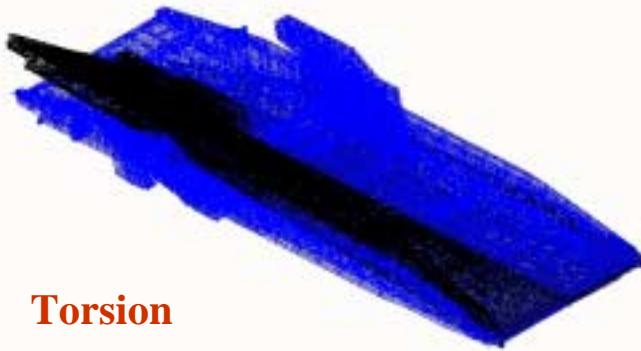
Detors One Tank - Case #3 Mode 4 Freq=4.6309 (Eigenvectors, Translational)



Boundary Condition Case #3 One Tank First 3 Elastic Modes

MSC Poten2308 r208 File#01 14:29:22

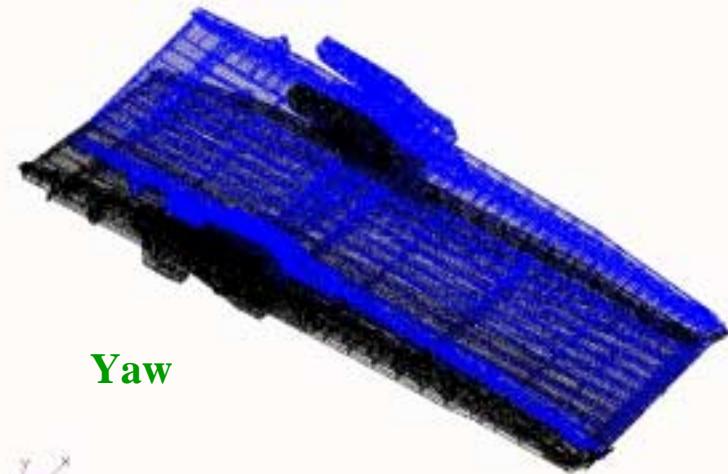
Debore Two Tanks - Case #3 Mode 2 Freq=1.4832 Eigenvectors, Time Unload



Torsion

MSC Poten2308 r208 File#01 14:29:39

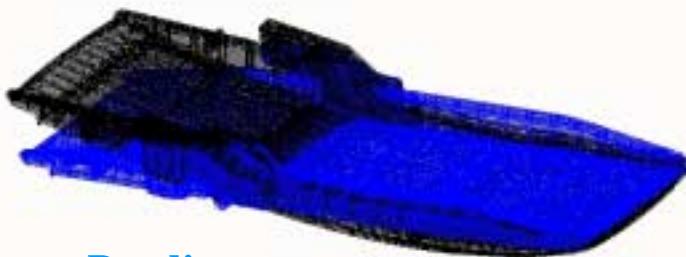
Debore Two Tanks - Case #3 Mode 2 Freq=1.4832 Eigenvectors, Time Unload



Yaw

MSC Poten2308 r208 File#01 14:30:36

Debore Two Tanks - Case #3 Mode 4 Freq=4.1137 Eigenvectors, Time Unload

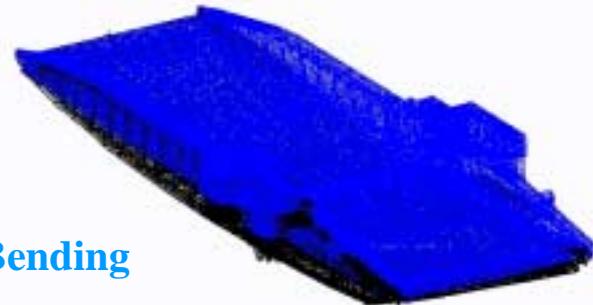


Bending

Boundary Condition Case #3 Two Tanks First 3 Elastic Modes

MSC.Poten2009 v2.08-Feb-01 13:38:57

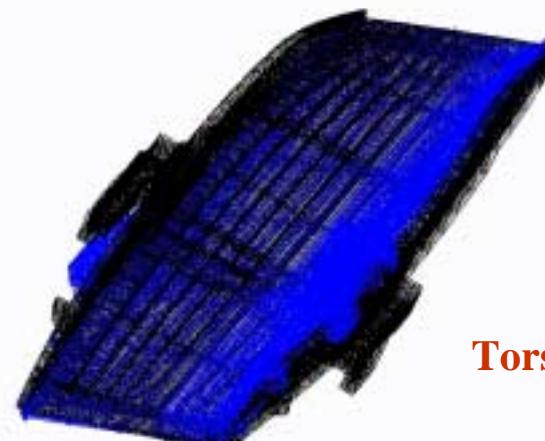
Deltors: One Tank - Case-4 Mode 1 Freq=2296.8 Eigen/vectors, Translational



Bending

MSC.Poten2009 v2.08-Feb-01 13:38:14

Deltors: One Tank - Case-4 Mode 2 Freq=2040.6 Eigen/vectors, Translational



Torsion

MSC.Poten2009 v2.08-Feb-01 13:39:28

Deltors: One Tank - Case-4 Mode 3 Freq=3480.3 Eigen/vectors, Translational



Yaw

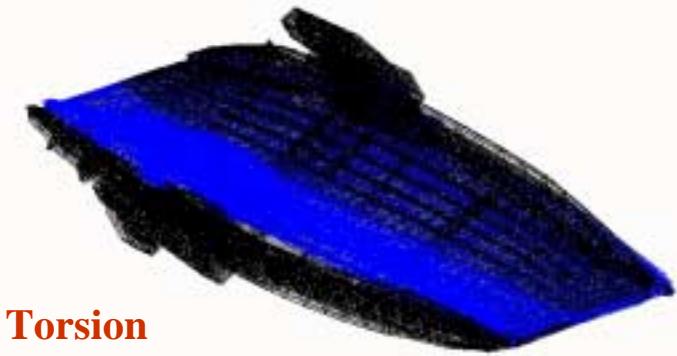
Boundary Condition Case #4 One Tank First 3 Elastic Modes

MSC.Poten2308r208-Field-01.14:38:15
Debora-Two Tanks - Case #4 Mode 1 Freq=0.2581 Eigenvectors, Translation



Bending

MSC.Poten2308r208-Field-01.14:38:22
Debora-Two Tanks - Case #4 Mode 2 Freq=0.5252 Eigenvectors, Time (Global)



Torsion

MSC.Poten2308r208-Field-01.14:37:10
Debora-Two Tanks - Case #4 Mode 3 Freq=0.3340 Eigenvectors, Time (Global)



Yaw

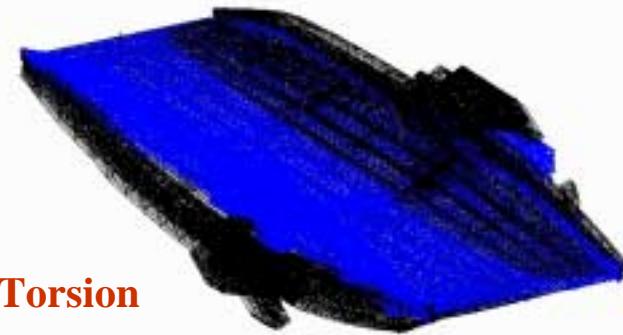
Boundary Condition Case #4 Two Tanks First 3 Elastic Modes

MSC.Polaris 2008 r2.06-Feb-01 13:45:59
Detours: One Tank - Case II, Mode 1 Freq = 2.2508 Eigen/vectors, Translational



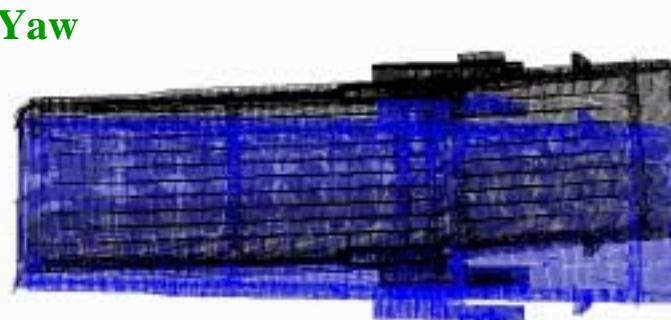
Bending

MSC.Polaris 2008 r2.06-Feb-01 13:45:54
Detours: One Tank - Case II, Mode 2 Freq = 2.38 Eigen/vectors, Translational



Torsion

MSC.Polaris 2008 r2.06-Feb-01 13:46:46
Detours: One Tank - Case II, Mode 3 Freq = 3.0120 Eigen/vectors, Translational

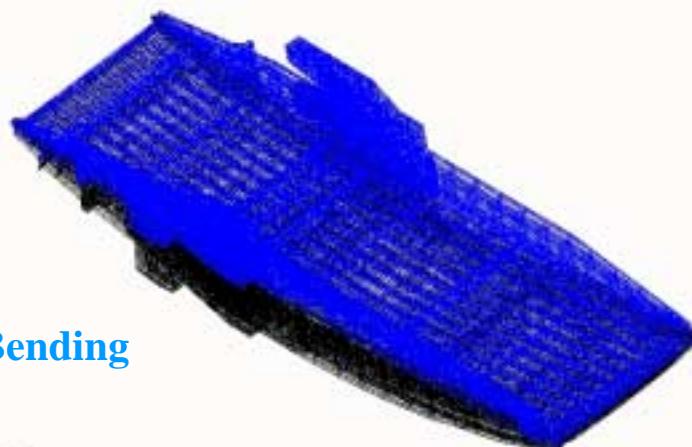


Yaw

Boundary Condition Case #5 One Tank First 3 Elastic Modes

MSC.Poten2308r208.Field-01.15.01.26

Detone Two Tanks - Case #5 Mode 1 Freq=25862 Eigenvectors, Time Interval

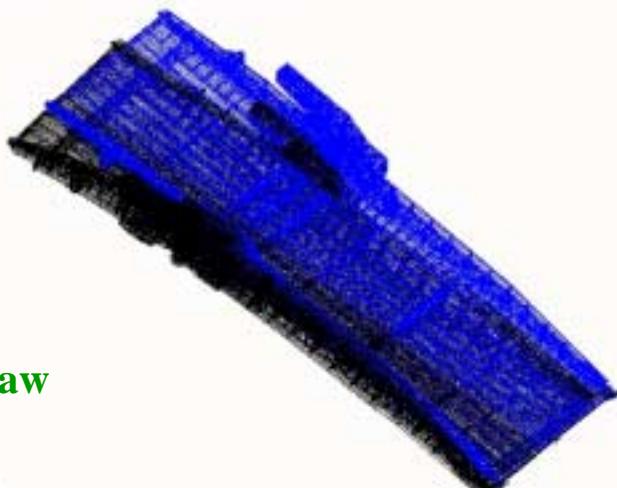


Bending



MSC.Poten2308r208.Field-01.15.01.41

Detone Two Tanks - Case #5 Mode 2 Freq=2615 Eigenvectors, Time Interval



Yaw



MSC.Poten2308r208.Field-01.15.01.12

Detone Two Tanks - Case #5 Mode 3 Freq=34466 Eigenvectors, Translation



Torsion



Boundary Condition Case #5 Two Tanks First 3 Elastic Modes

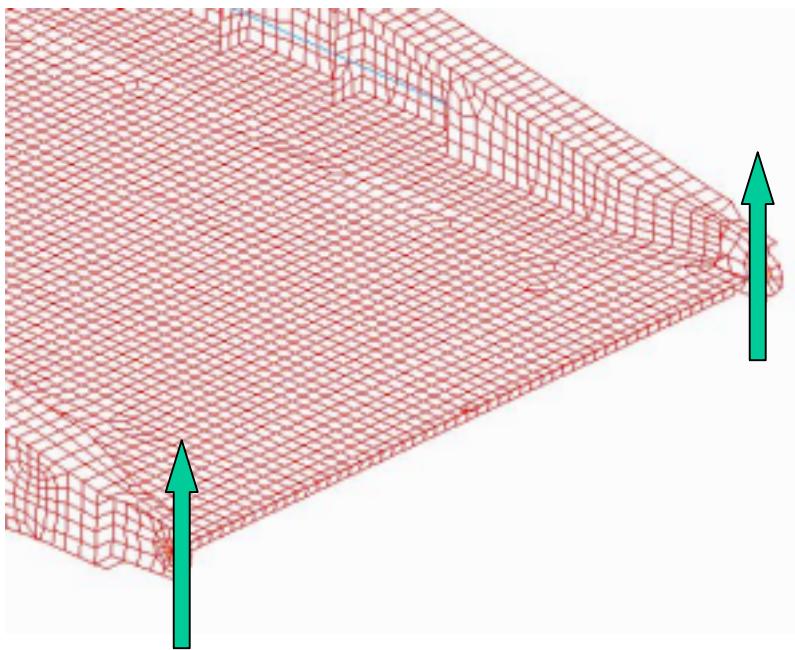
Dynamic Stress

- Simulated wave-induced RORO motions applied
- Sea-State 3: **2.5 ft wave height**
 Also 1.25 ft and 0.625 ft
- Prescribed motion periods / frequencies:

Seconds:	20	6.67	4.0	2.86
Hertz:	0.05	0.15	0.25	0.35

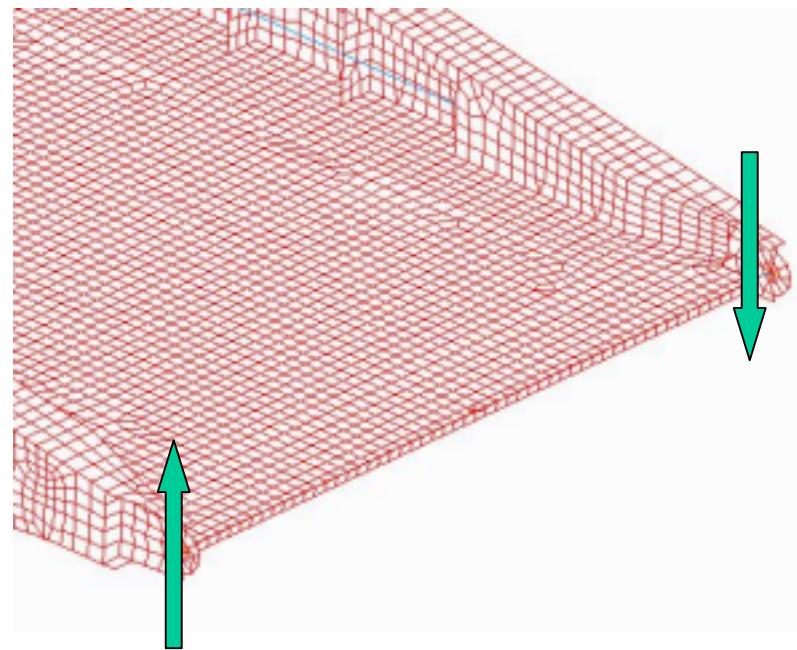
- Heave and roll (separate load cases)
- Boundary condition Case #5
- Worst case: Roll input at 0.35 Hz

Load Cases: Heave & Roll



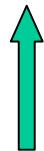
Heave Input

(In-phase displacement inputs)



Roll Input

(Out-of-phase displacement inputs)

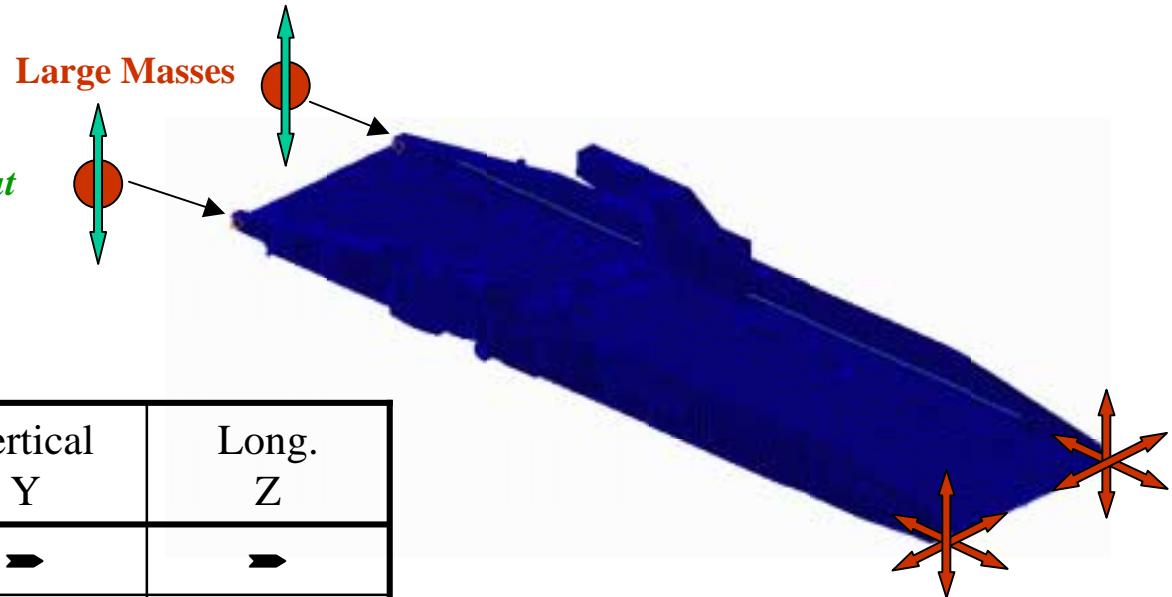


= Indicates harmonic displacement input

Boundary Conditions

- Fully-pinned at ship end + large masses at barge end
- Each large mass $\cong 10^6 \times$ Total Ramp+Tank mass

Green Arrows indicate motion input



Grid	Lateral X	Vertical Y	Long. Z
40288	➡	➡	➡
40289		➡	➡
40769		Large Mass	
40805		Large Mass	

Red Arrows indicate restrained DOF

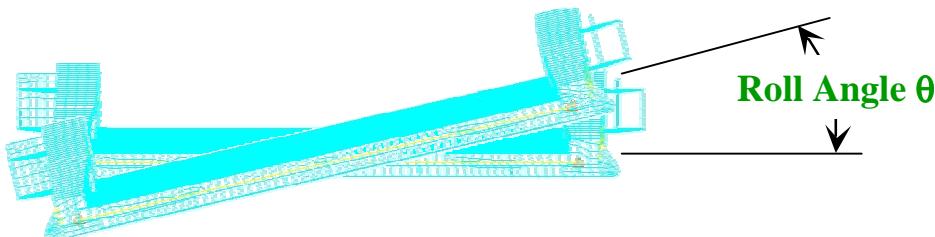
Dynamic Stress Summary

- Wave amplitude 2.5 ft (Sea State 3)
- Wave Period 2.86 second (0.35 Hz)

Wave 2.5 ft	Peak Stress in PSI	
Loading	Heave Input	Roll Input
No Tank	3800	130,000
One Tank	6100	391,000
Two Tanks	7000	463,000

Limiting Roll Angle

- Determine limiting roll angle based on peak stress



Barge-end of ramp:

0° imposed roll Angle

$$\theta = \tan^{-1} \left(\frac{2 * \text{waveamplitude}}{\text{ramp width}} \right) \left(\frac{180}{\pi} \right)$$

Cape T ramp width: 26 ft

Peak Stress vs. Roll Angle (see analyses plots following)

Roll Angle (degrees)	Wave amplitude (feet)	Peak Stress (Kpsi)
10.9	2.5	463
5.5	1.25	231
2.8	0.625	116

Stress-Limited Roll Angle

- Peak stress vs. roll angle is linear
- Determine roll angle vs. peak stress

$$\sigma \approx a\theta + b \quad \text{where} \quad \begin{aligned} a &= 42.7984 \\ b &= -4.1687 \end{aligned} \quad \rightarrow \quad \theta = (\sigma - b)/a$$

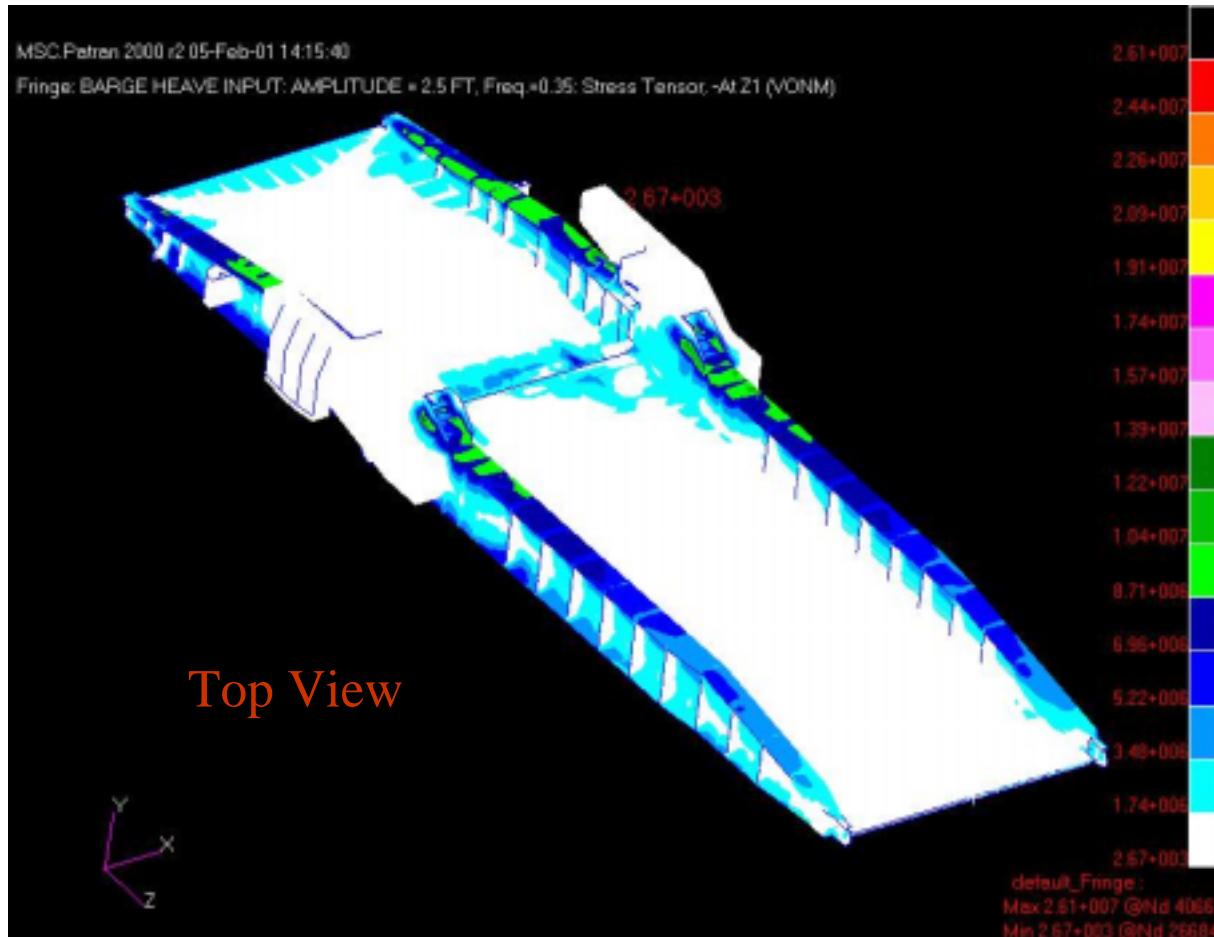
- What is max roll angle for $\sigma_{\max} = 40\text{kpsi}$?

$$\theta = (40 - b)/a = 1.0320^\circ$$

Requirement of peak stress of 40 kpsi limits barge roll to 1.032 degrees.

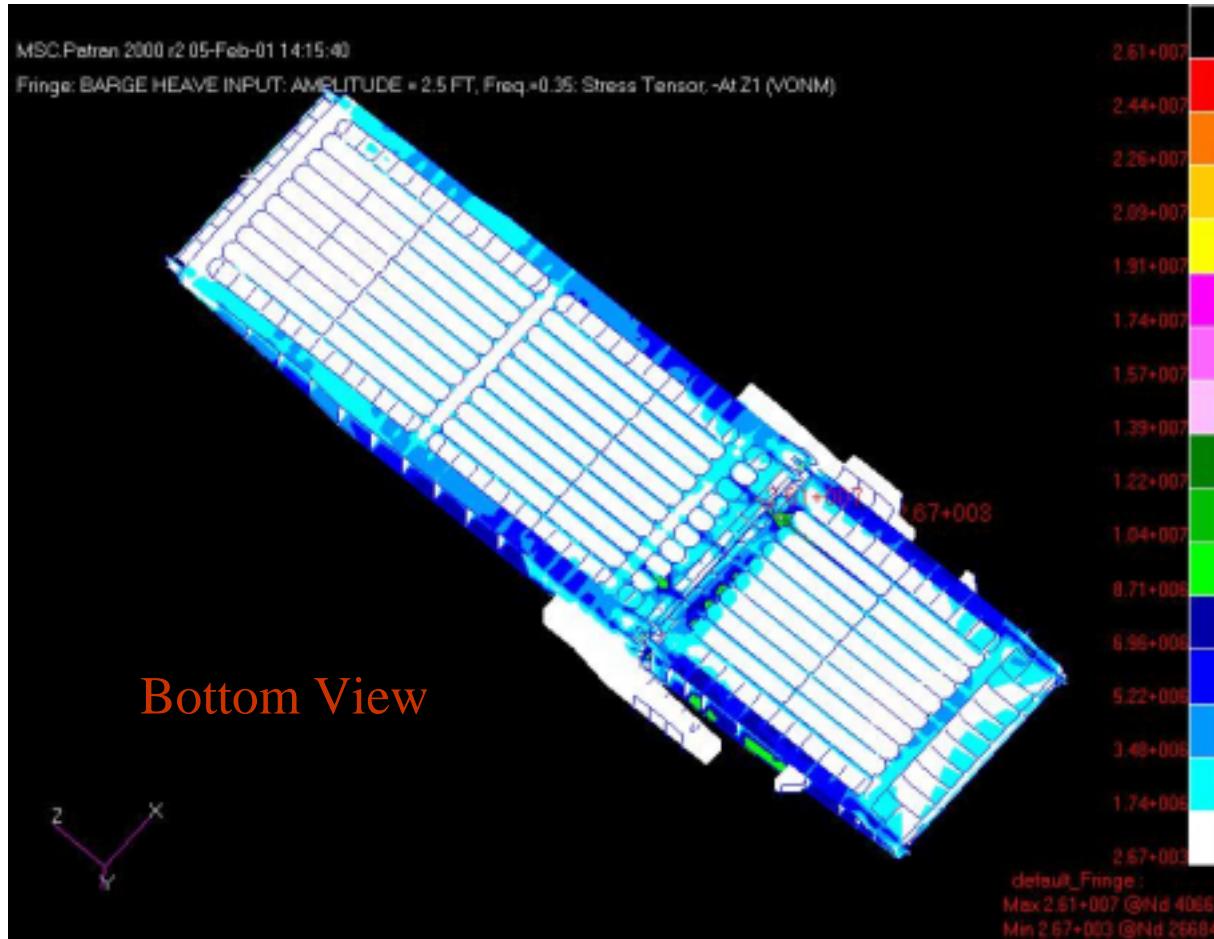
Dynamic Stress – No Tank – Heave Input

- Heave Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 2.61×10^7 Pa $\cong 3800$ psi



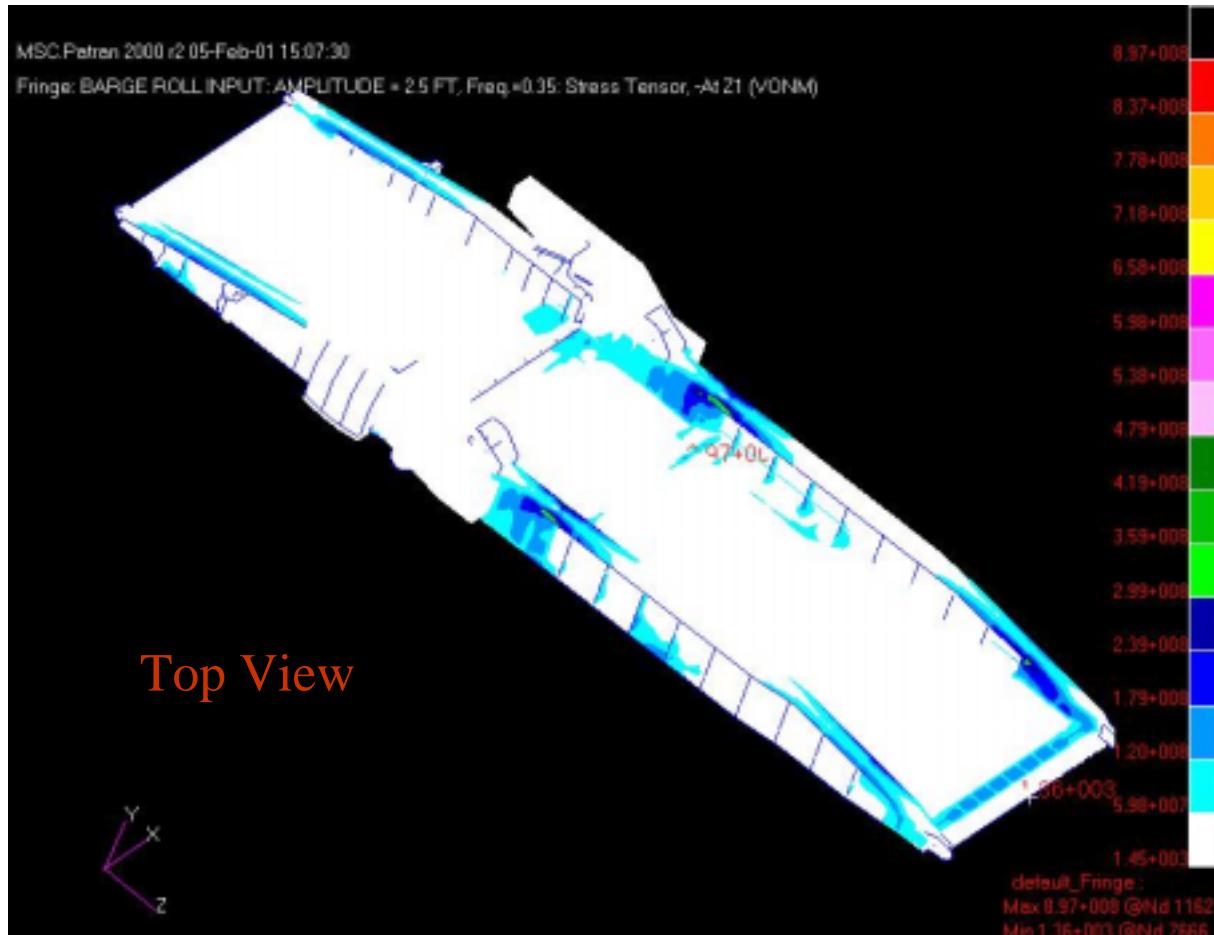
Dynamic Stress – No Tank – Heave Input

- Heave Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 2.61×10^7 Pa $\cong 3800$ psi



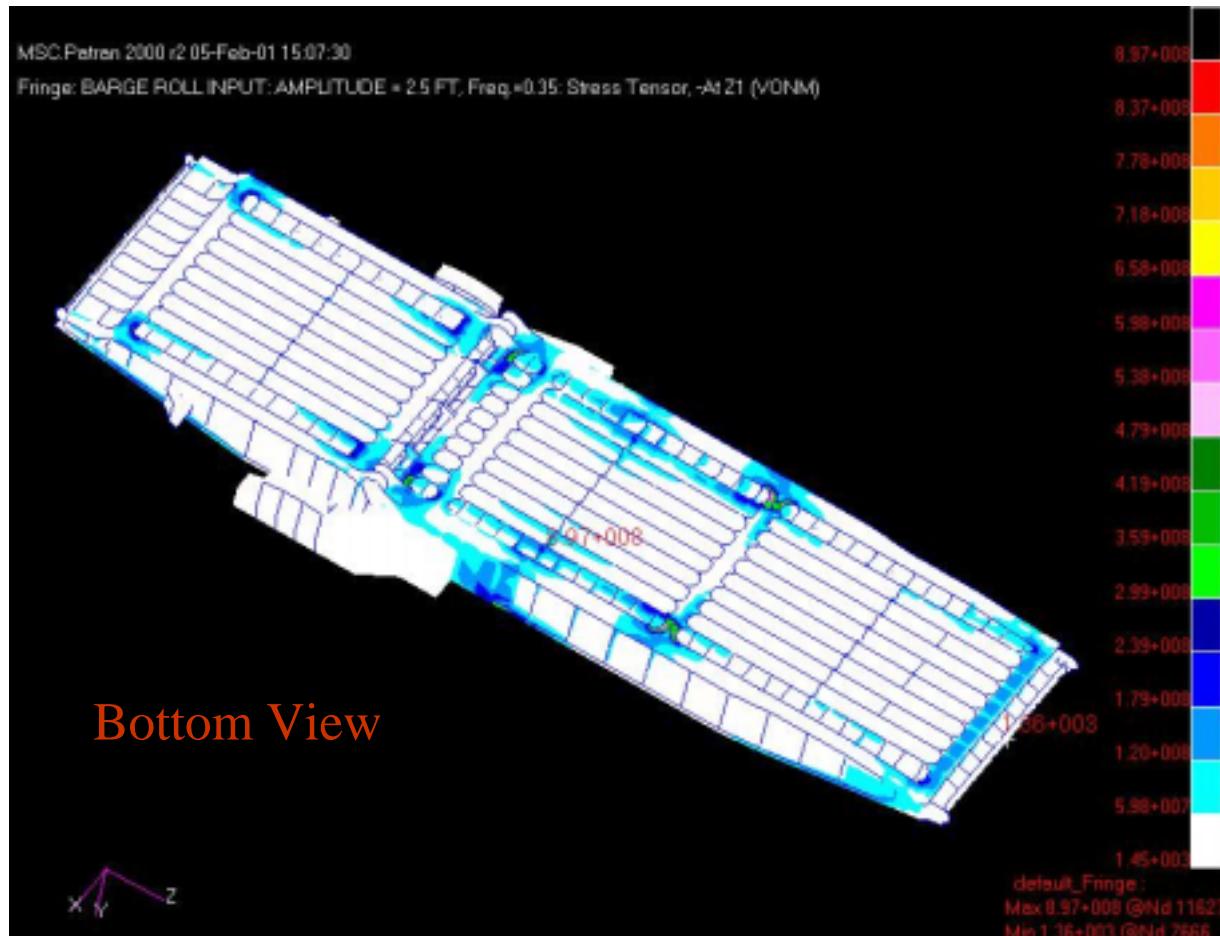
Dynamic Stress – No Tank – Roll Input

- Roll Input – 0.35 Hz – 2.5 ft wave
- Max Stress: $8.97 \times 10^8 \text{ Pa} \cong 130,000 \text{ psi}$



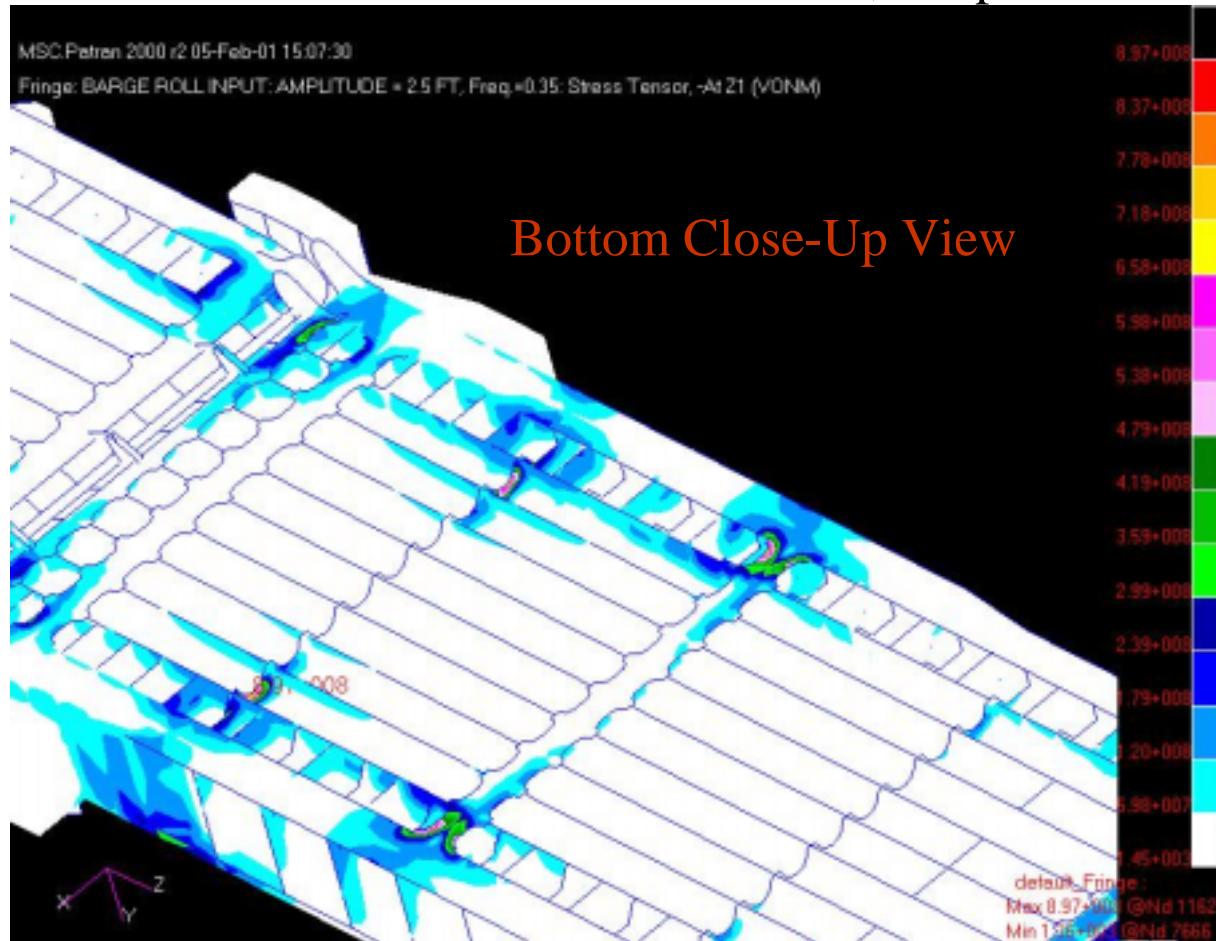
Dynamic Stress – No Tank – Roll Input

- Roll Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 8.97×10^8 Pa \cong 130,000 psi



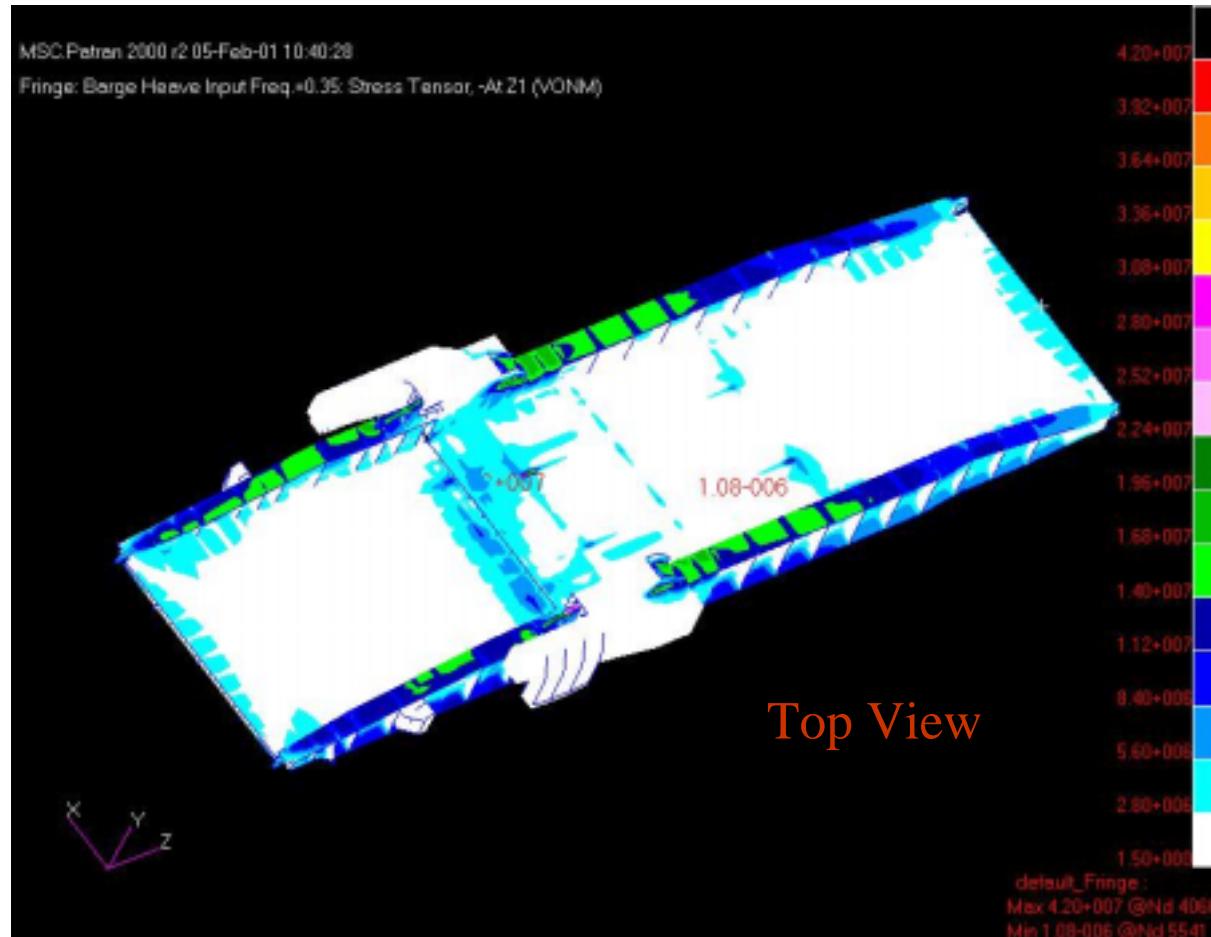
Dynamic Stress – No Tank – Roll Input

- Roll Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 8.97×10^8 Pa \cong 130,000 psi



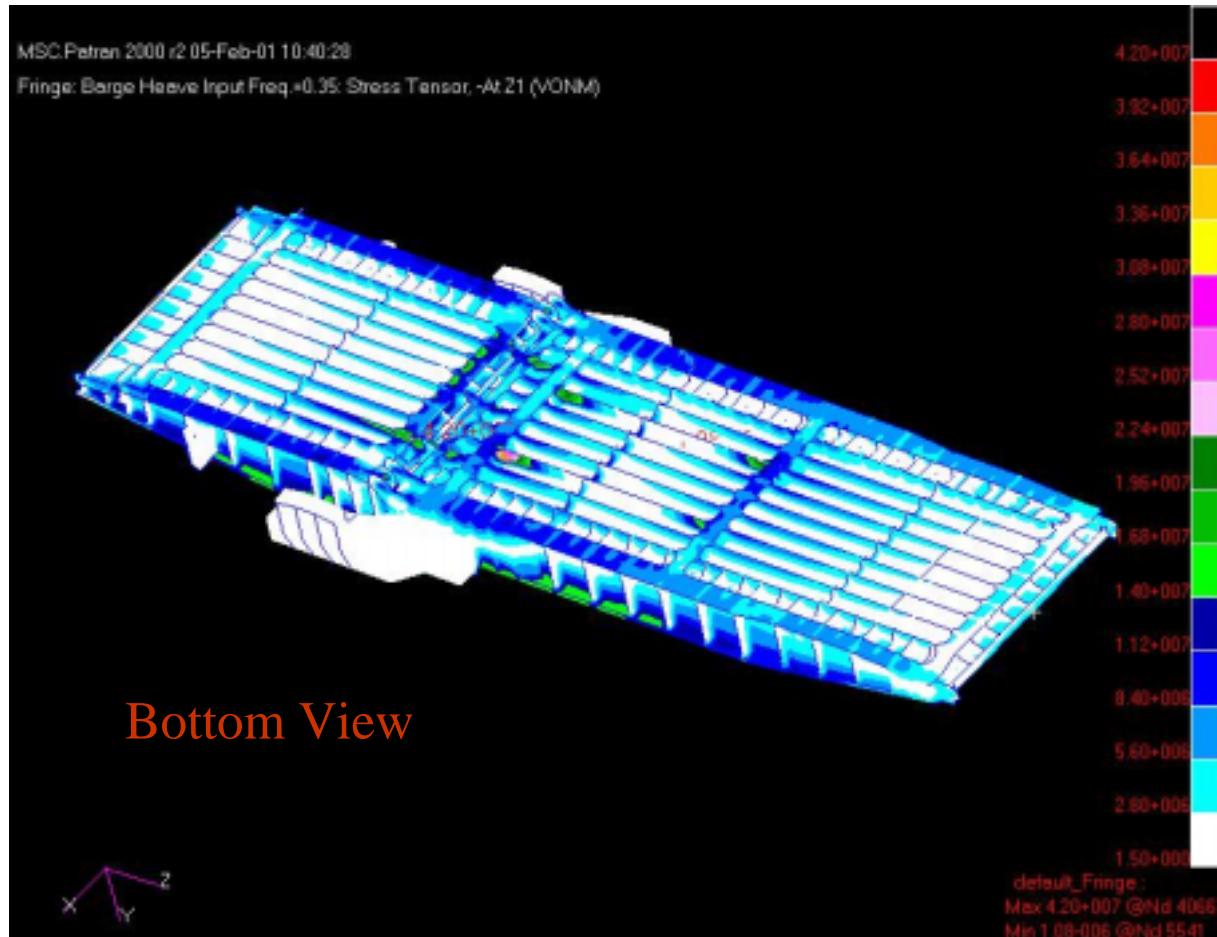
Dynamic Stress – One Tank – Heave Input

- Heave Input – 0.35 Hz – 2.5 ft wave
 - Max Stress: 4.20×10^7 Pa \cong 6100 psi



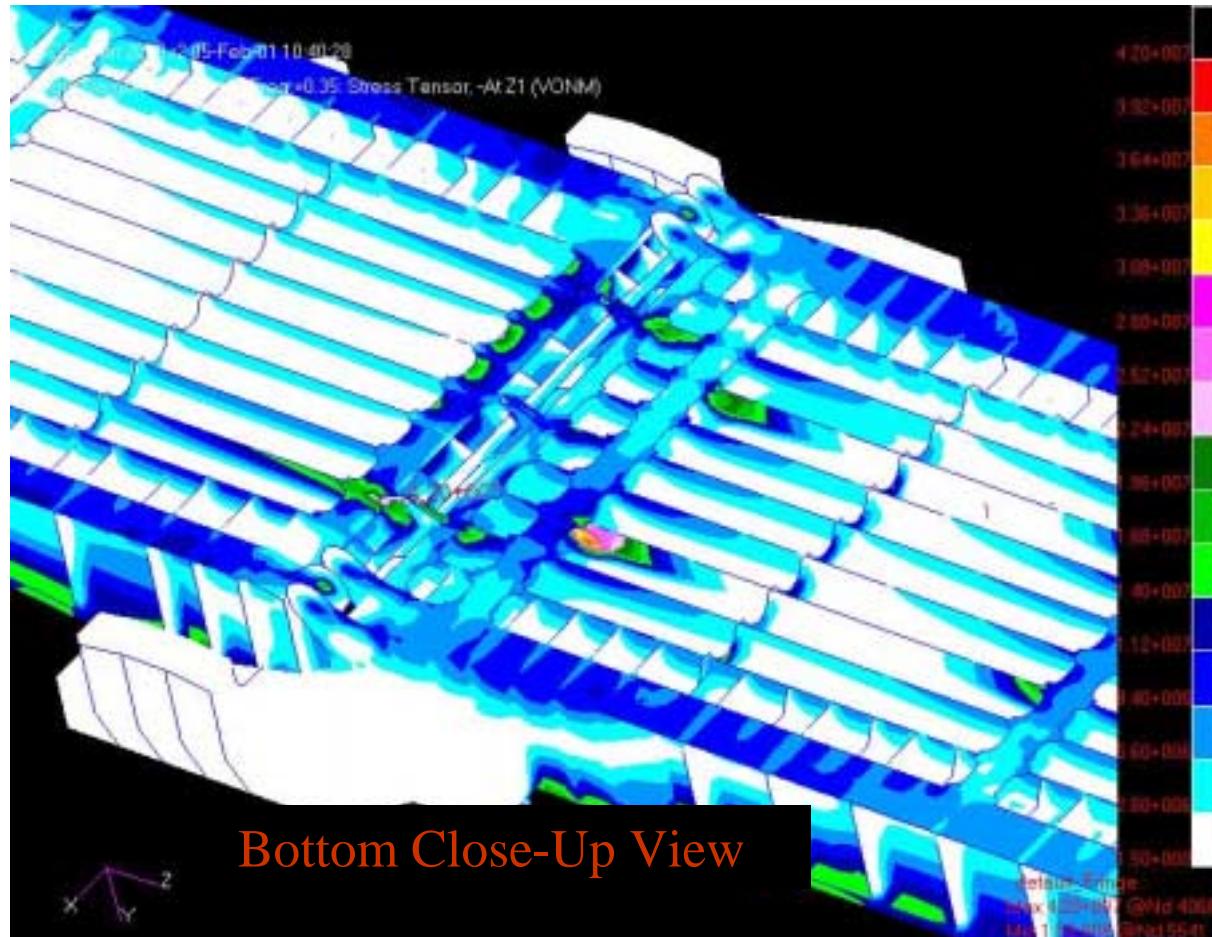
Dynamic Stress – One Tank – Heave Input

- Heave Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 4.20×10^7 Pa $\cong 6100$ psi



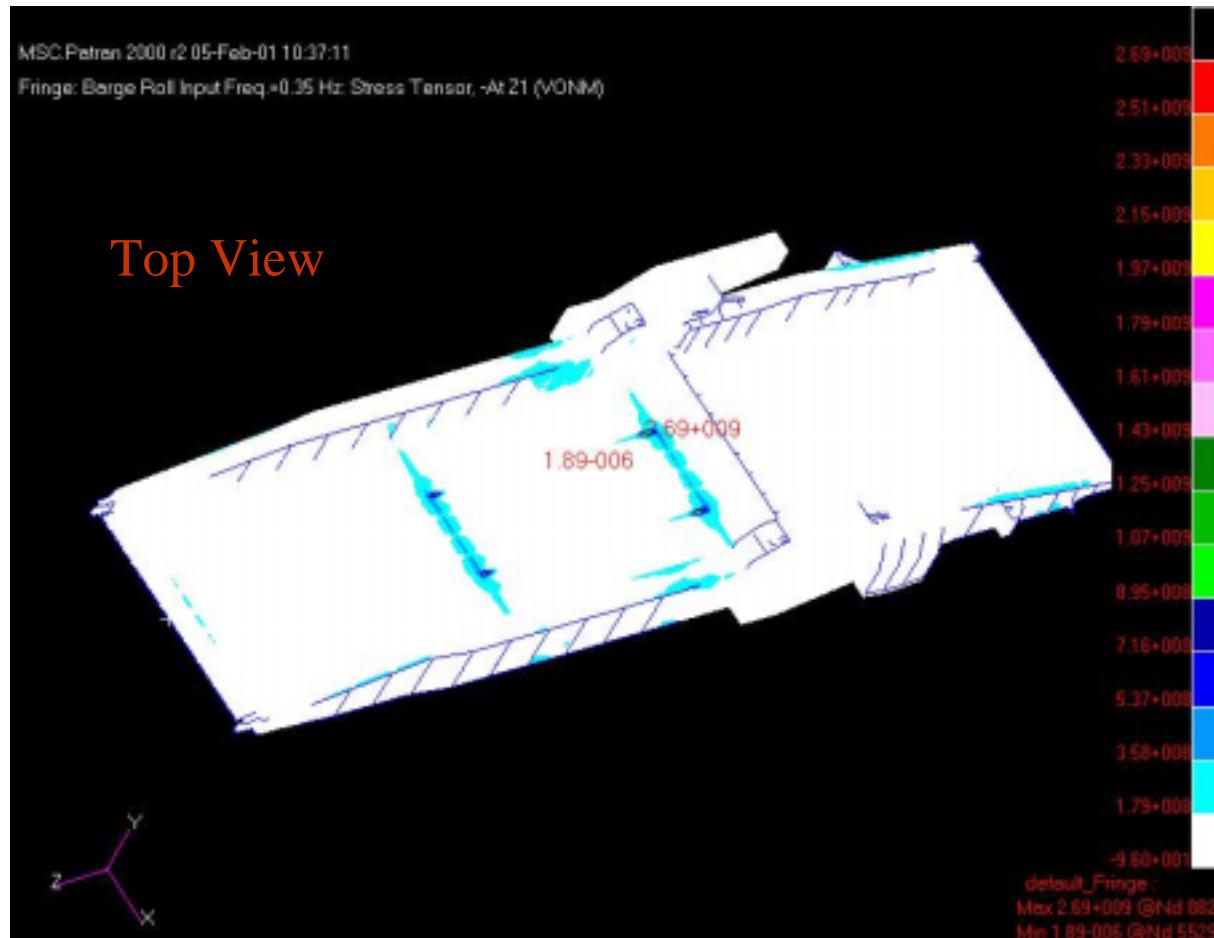
Dynamic Stress – One Tank – Heave Input

- Heave Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 4.20×10^7 Pa $\cong 6100$ psi



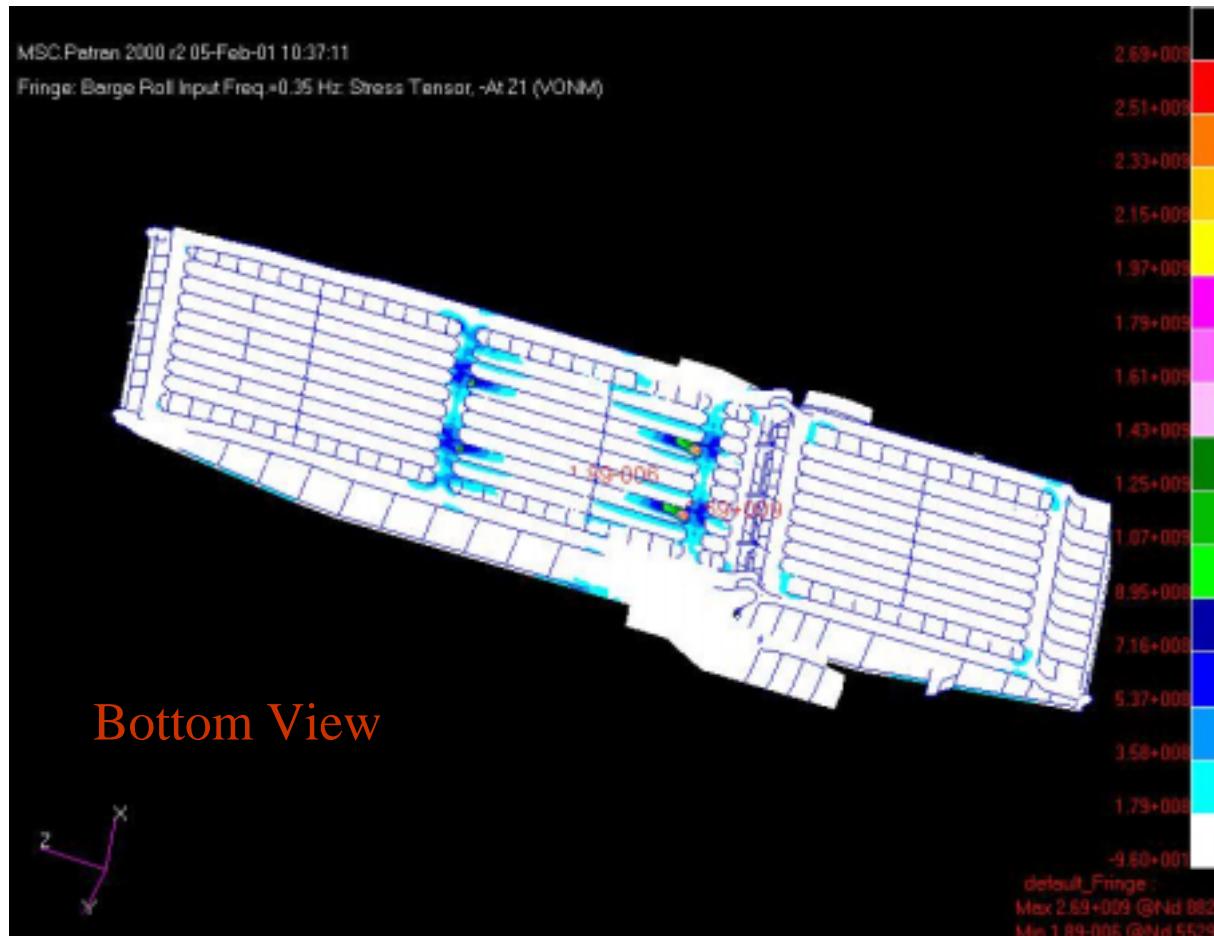
Dynamic Stress – One Tank – Roll Input

- Roll Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 2.69×10^9 Pa $\cong 391,000$ psi



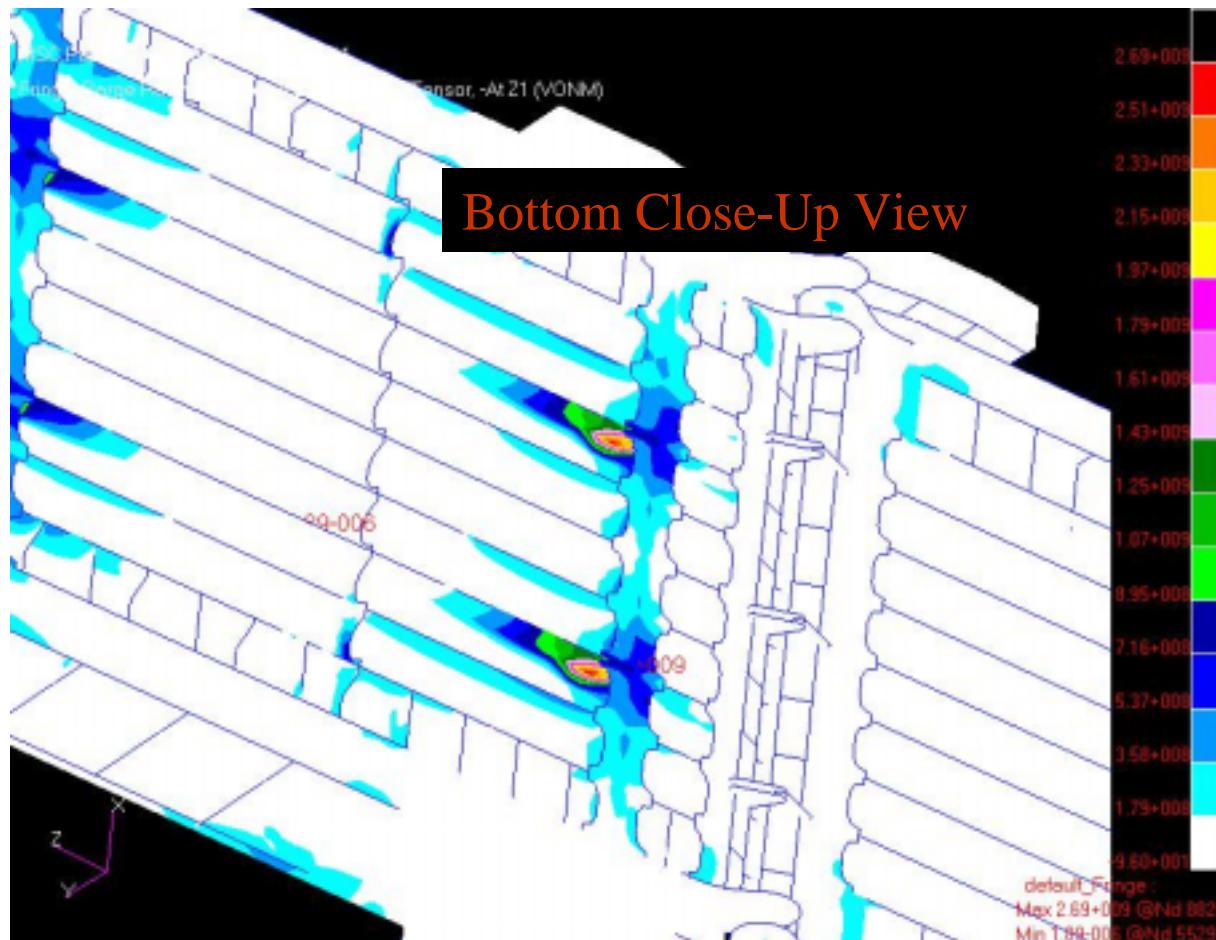
Dynamic Stress – One Tank – Roll Input

- Roll Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 2.69×10^9 Pa $\cong 391,000$ psi



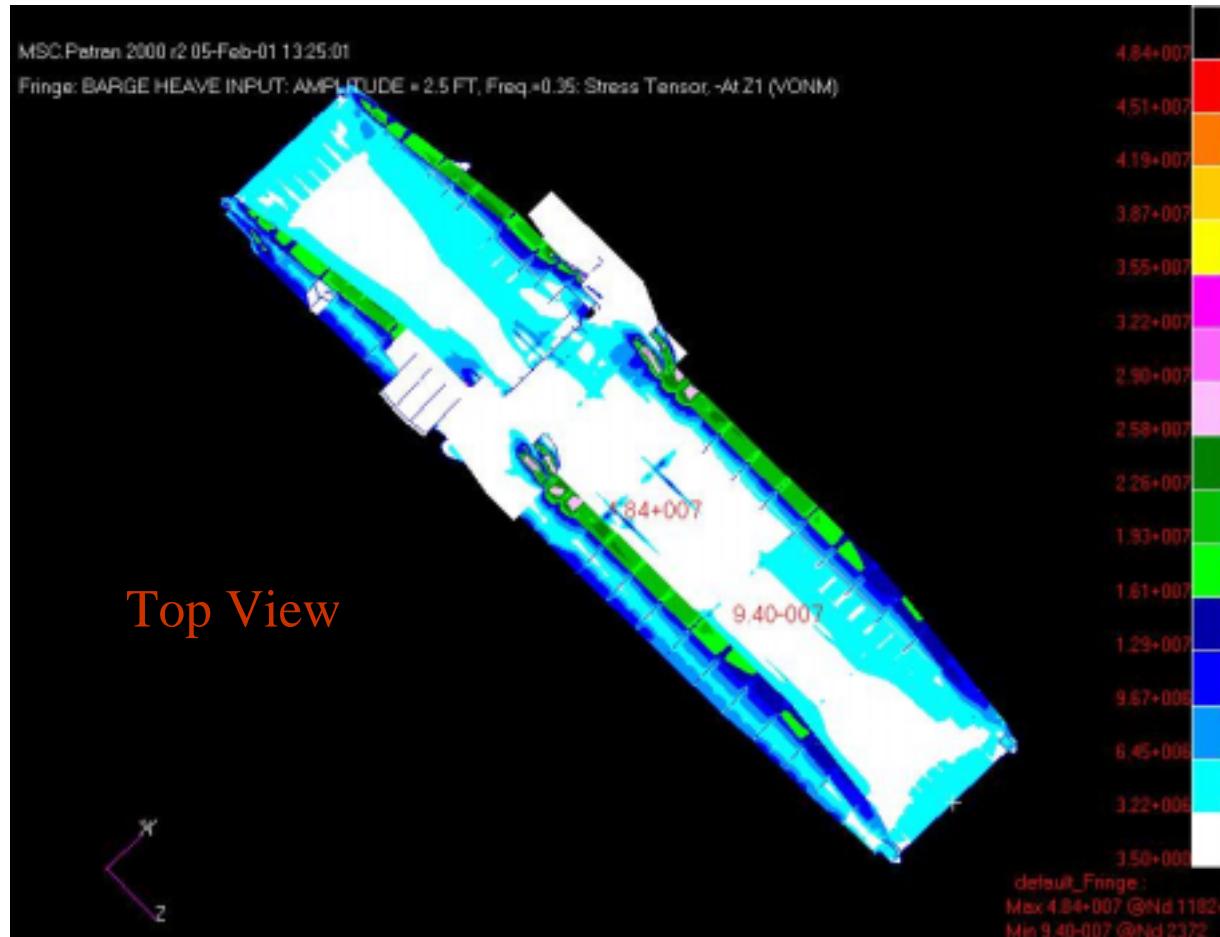
Dynamic Stress – One Tank – Roll Input

- Roll Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 2.69×10^9 Pa $\cong 391,000$ psi



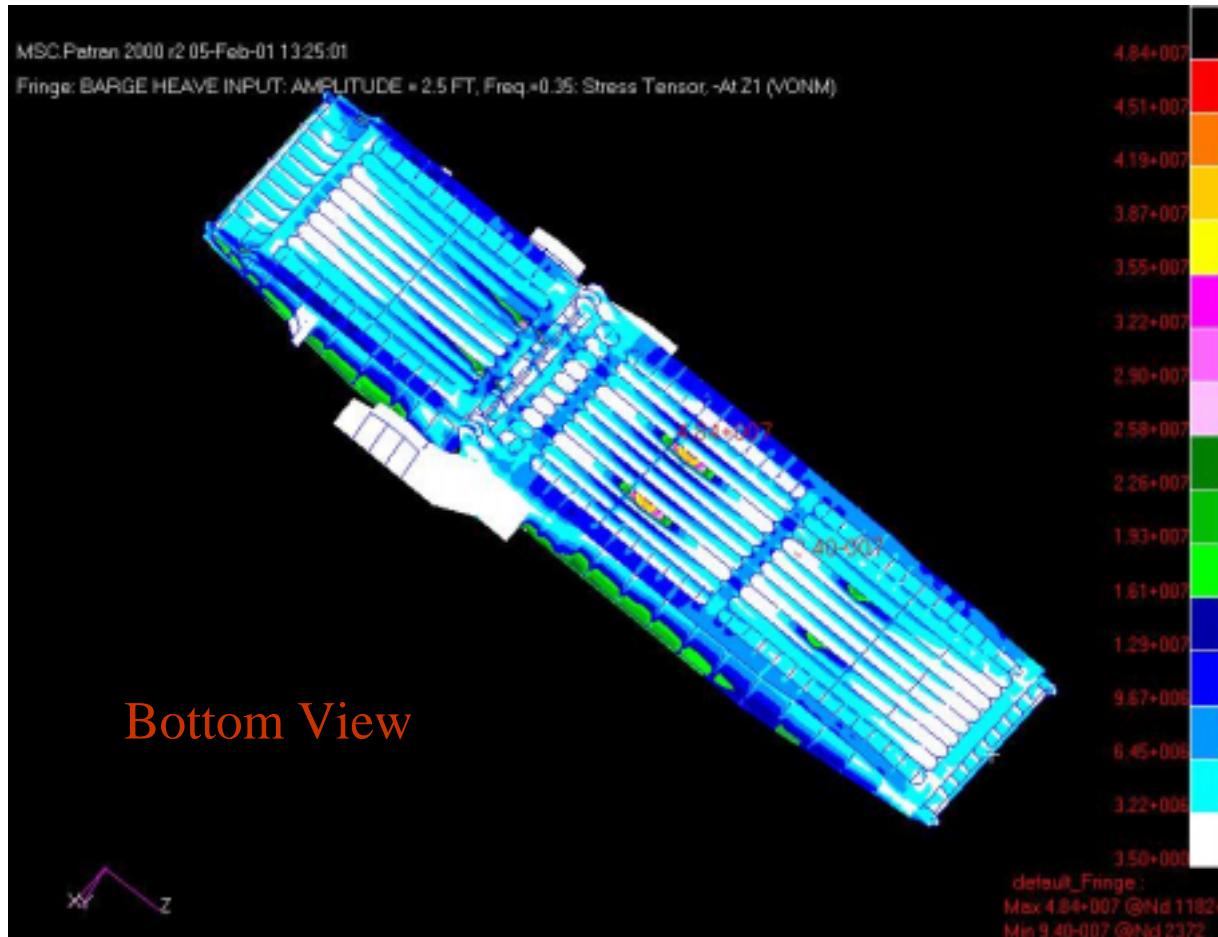
Dynamic Stress – Two Tanks – Heave Input

- Heave Input – 0.35 Hz – 2.5 ft wave
- Max Stress: $4.84\text{e}7 \text{ Pa} \cong 7000 \text{ psi}$



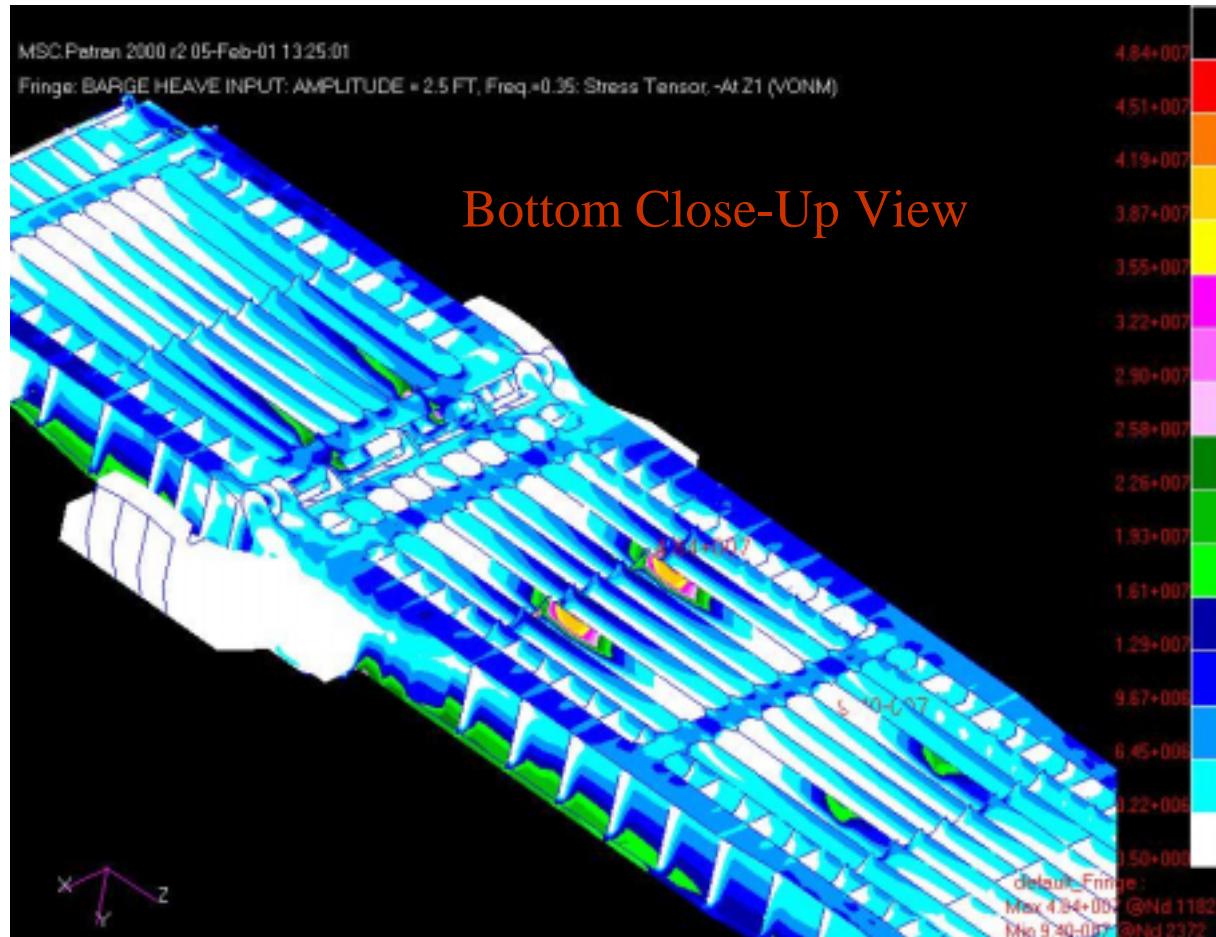
Dynamic Stress – Two Tanks – Heave Input

- Heave Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 4.84×10^7 Pa \cong 7000 psi



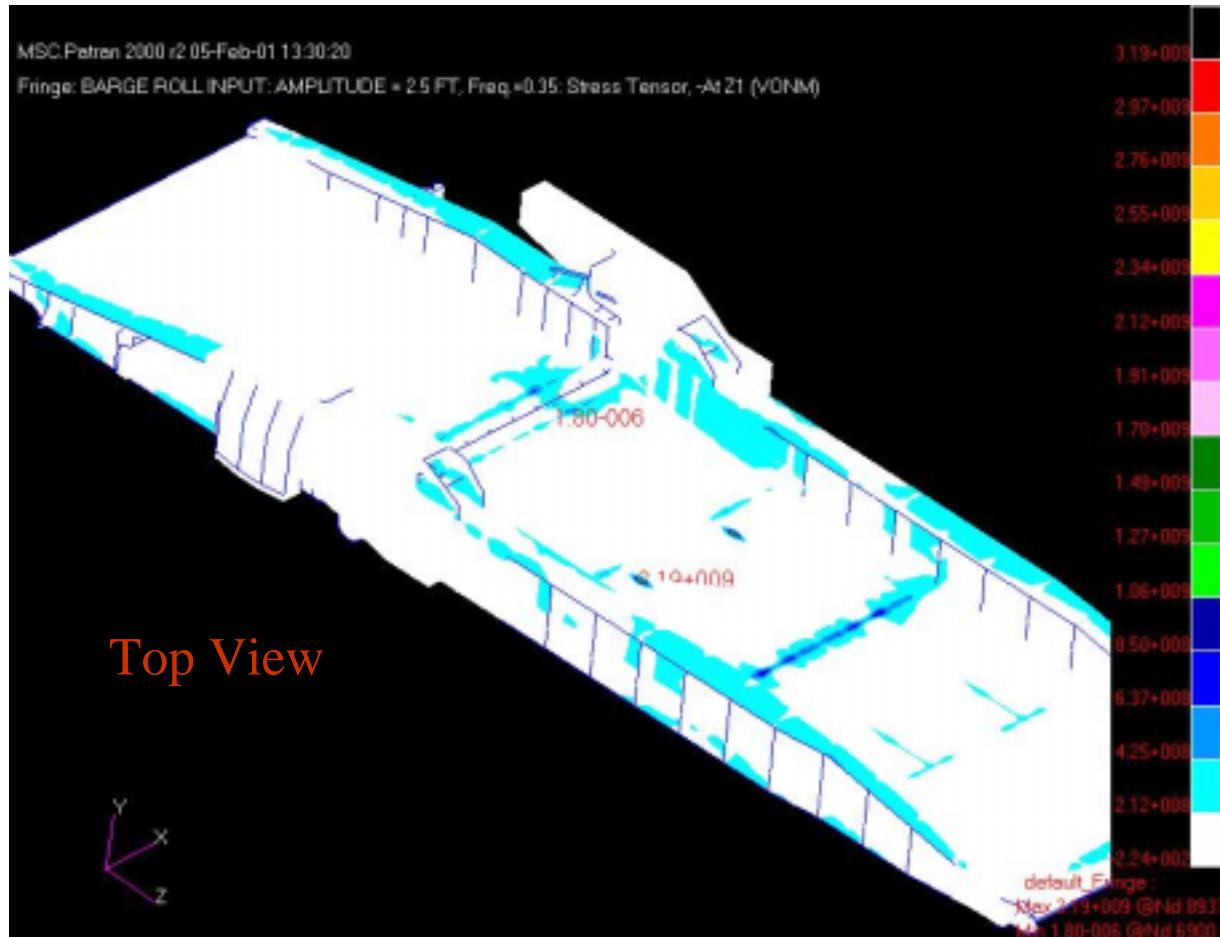
Dynamic Stress – Two Tanks – Heave Input

- Heave Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 4.84×10^7 Pa \cong 7000 psi



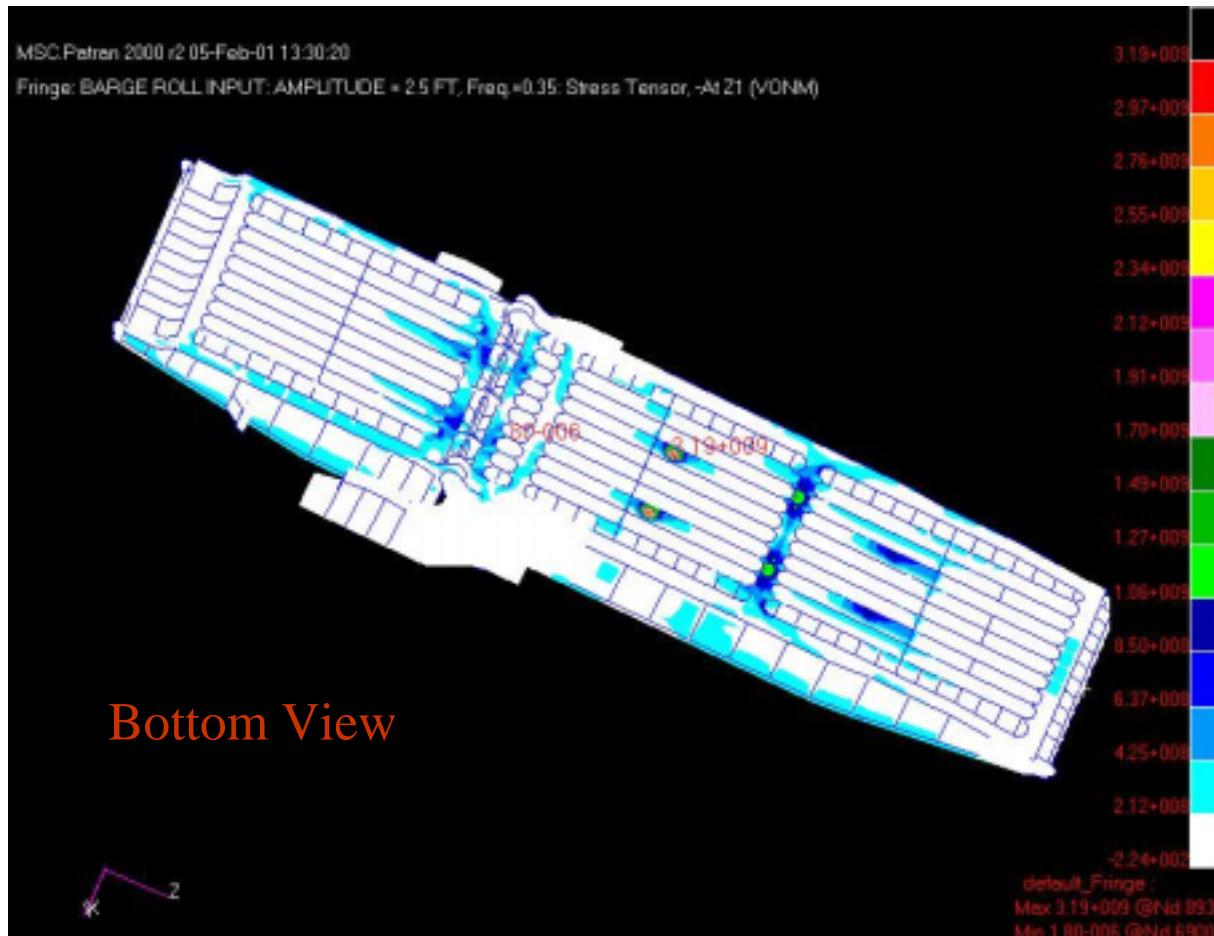
Dynamic Stress – Two Tanks – Roll Input

- Roll Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 3.19×10^9 Pa $\cong 463,000$ psi



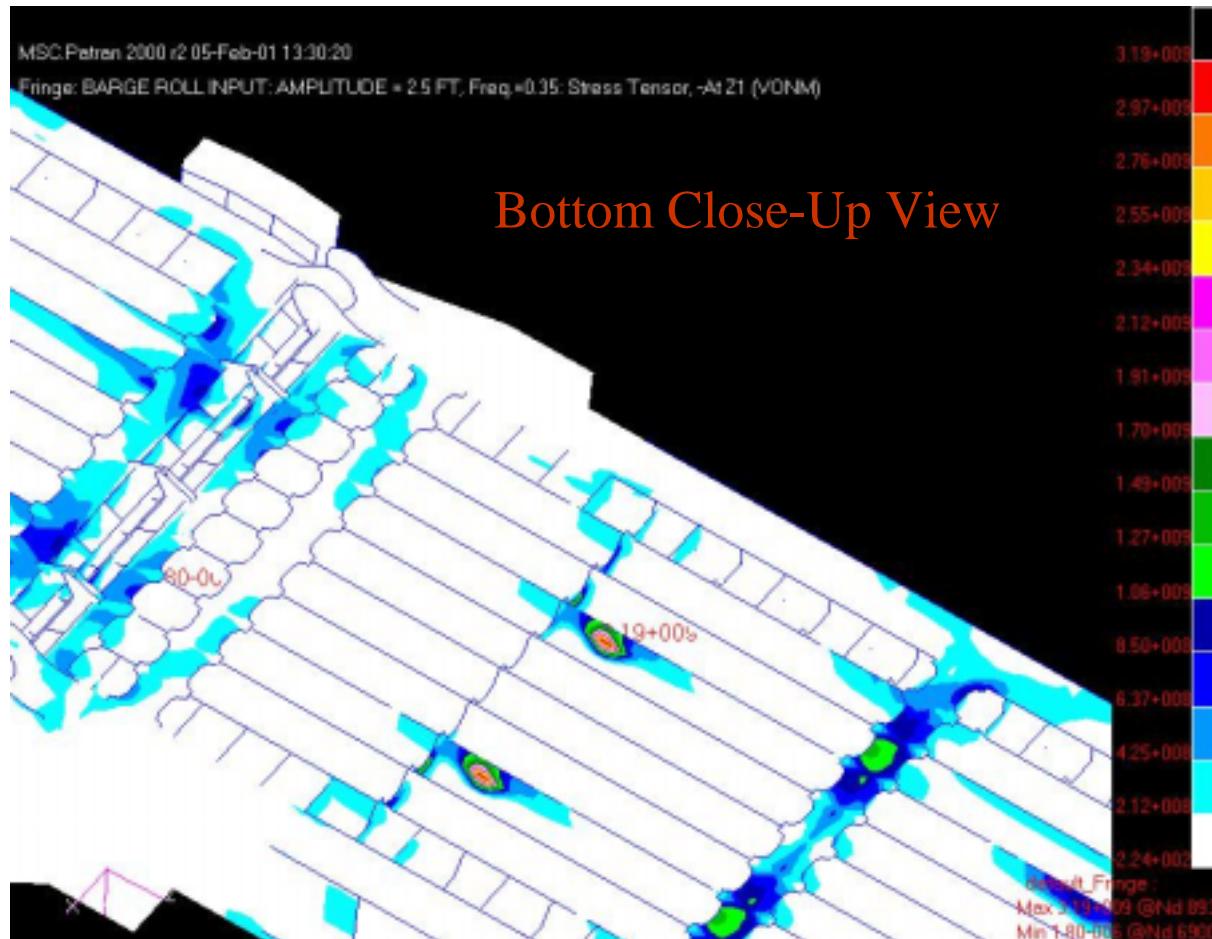
Dynamic Stress – Two Tanks – Roll Input

- Roll Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 3.19×10^9 Pa $\cong 463,000$ psi



Dynamic Stress – Two Tanks – Roll Input

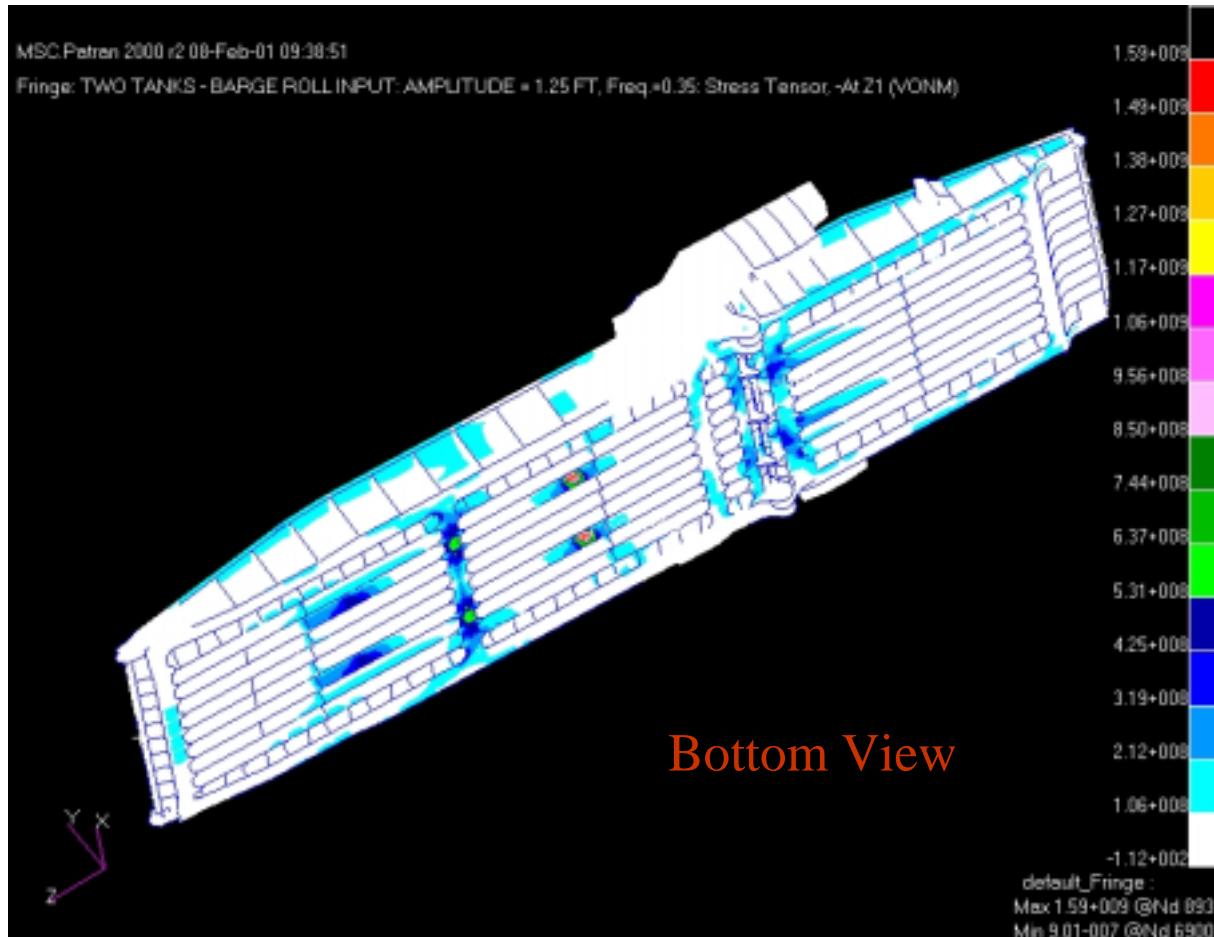
- Roll Input – 0.35 Hz – 2.5 ft wave
- Max Stress: 3.19×10^9 Pa $\cong 463,000$ psi



Dynamic Stress – Two Tanks – Roll Input

Input amplitude/2:

- Roll Input – 0.35 Hz – **1.25** ft wave
- Max Stress: 1.59×10^9 Pa $\cong 231,000$ psi



Dynamic Stress – Two Tanks – Roll Input

Input amplitude/4:

- Roll Input – 0.35 Hz – **0.625 ft** wave
- Max Stress: $7.99 \times 10^8 \text{ Pa} \cong 116,000 \text{ psi}$

